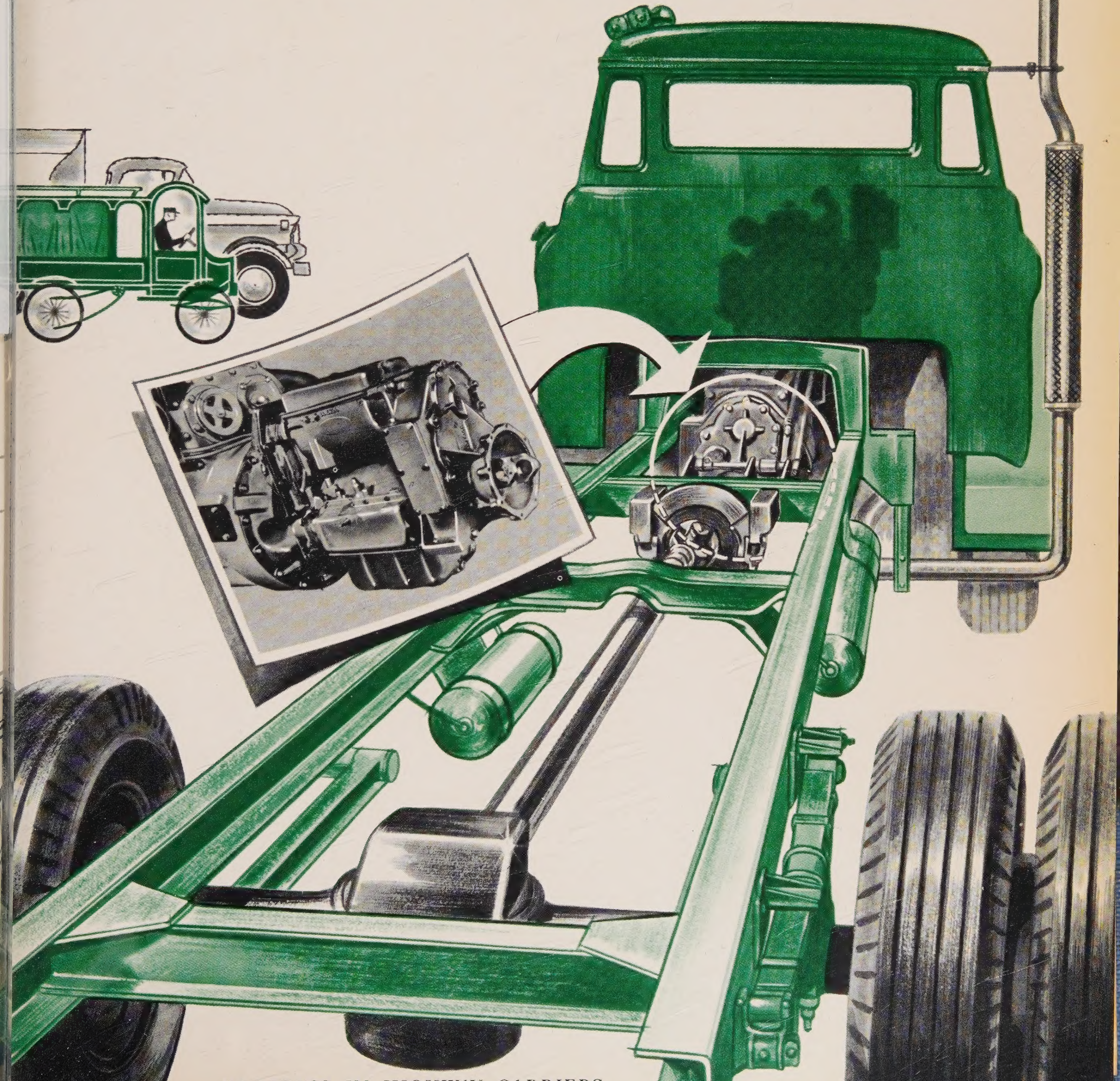
GENERAL MOTORS

Engineering JOURNAL

Volume 3 March-April 1956 Number 2

for educators in the fields of engineering and allied sciences



PROGRESS IN HIGHWAY CARRIERS

On Engineers in Manufacturing

In these days when the demand for engineers greatly exceeds the supply, we have been asked the question, "Why is it that you are using so many graduate engineers in the manufacturing side of the business?"—and the corollary question, "Are you thereby using their training to the fullest?"

We believe there are two basically sound and satisfactory answers to these questions. First, as our stylists and design engineers continue to apply the advances of science and technology in the accomplishment of their objectives, the manufacturing processes become increasingly complex. This result is inevitable; therefore, successful manufacturing depends more and more on the trained mind for the solution of the daily problems which face the production supervisor.

Our products, whether they be automotive or other, are no longer a combination of relatively simple mechanical components but are rather a combination of electrical, hydraulic, and electronic, as well as mechanical, units, each of which requires more than a smattering of education to understand their composite functioning. Here, we refer to education not with emphasis on technical knowledge so much as on what we call "a well disciplined analytical approach." The graduate engineer is best equipped by training to supply this approach.

The second answer to the questions posed is found in the satisfaction of each man's urge to find the field of greatest personal attainment and achievement without regard for the particular path he followed in receiving his formal education.

In order to obtain his degree the undergraduate must necessarily concentrate in the particular field of his choice and discipline his mind to stay within well-defined boundaries of study and investigation as required by curriculum.

Following graduation, these restraints are removed, and he is then free to apply his learning in that area of work which captures his interest and in which he feels he can exercise his talents to the fullest, and further, to move on to work entirely unrelated to his formal education in his unrelenting effort to satisfy a just ambition.

It was in the exercise of this freedom to search out and find the way to greatest achievement that DaVinci became as renowned a mathematician as he was a painter, and in our own day has brought to Herbert Hoover greater acclaim as a statesman than as a successful engineer.

J. J. Cronin

J. J. Cronin,
Vice President in Charge
of Manufacturing Staff

THE COVER

This issue's cover design by artist John Dickey—another depicting developments in transportation—emphasizes the strides that have been made in the development of power train components for trucks. The progress is represented by the comparison of the low-powered, sprocket and chain drive truck of the early 1900's to a typical truck of today. Of the many significant developments in highway carriers over the past 50 years not the least is the automatic transmission. For example, the new Twin Hydra-Matic automatic transmission for GMC Trucks, developed by GM's Detroit Transmission Division engineers, provides a sufficient number of closely spaced, automatically selected gear ratios to meet the wide range of torque-speed combinations today's heavy-duty hauling requires. Other engineering developments, such as Diesel engines, better suspension, more rigid frame structures, and better economy, as well as more attractive styling have contributed importantly making present-day highway carriers a vital part of the nation's transportation system.

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The Development of New and Unique Manufacturing Techniques for the Production of Passenger-Car Frames

By GODFREY BURROWS
Chevrolet
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Transforming a round tube into a rectangular frame side rail

Engineers engaged in manufacturing constantly strive to achieve new and better methods to produce a product—methods which result in material savings and decreased manufacturing costs. In most cases, a better method of production stems from a basic idea. This basic idea must then be carried through various stages—planning, machine tool design, testing, and experimental processing—before the final stage of actual production is achieved. The 1955 Chevrolet passenger car frame, which was completely new in design to match the car's new body styling and redesigned major chassis components, is a case example of developing a better method of manufacture from a basic idea. The frame's design was based on side rails of rectangular section.

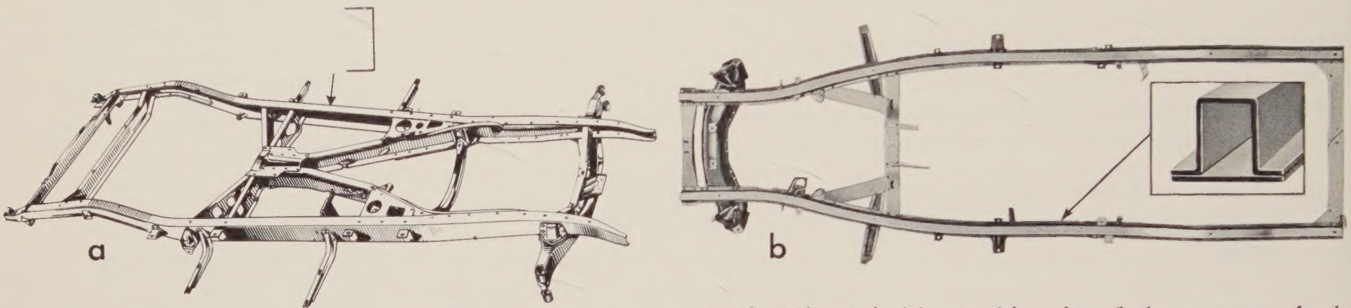


Fig. 1—Through the years the side rail and cross member components of passenger car frames have undergone change to meet design requirements of strength, rigidity, and minimum weight and to afford proper support for the body and chassis components. The frame side rails for the 1934 Chevrolet **(a)** were of the channel-section type design. The 1949 Chevrolet frame **(b)** employed a box-girder type of side rail design.

The structural center of an automotive vehicle is the frame which, in addition to carrying load, furnishes support for the body and such chassis components as the engine, transmission, axles, springs, and steering gear. The frame serves to maintain correct relationship of all chassis components and provides freedom from stress, strain, and wear that may be caused by their operation in a misaligned condition.

Through the years passenger car frames have undergone change both in the structural material used for frame components and the methods employed for their fabrication. To meet strength, rigidity, and minimum weight requirements frame side rails and cross members also have undergone change in design. Fig. 1 shows the 1934 and 1949 Chevrolet passenger car frames and illustrates the changes made in frame side rail and cross member design.

Major changes in such items as a passenger car's body styling, engine design, suspension system, or any other items directly depending upon the frame for support necessitate a change in the frame's design from the standpoint of strength, rigidity, and minimum weight requirements and also the number and location of cross members and support brackets required. A passenger car which undergoes a complete redesign in all of its major chassis components and body styling requires a completely new frame design. This was the case with regard to the 1955 Chevrolet passenger car.

New Frame Design and Method of Manufacture

Approximately fourteen months prior to the introduction of the 1955 Chevrolet passenger car, work was initiated on the design and development of the new frame. Discussions centering about the new frame program had as their objective the development of a high quality frame having simplicity of design.

After much discussion and joint effort on the part of engineers engaged in both the engineering and manufacturing aspects of the development program, a new frame design was finalized which was based on rectangularly shaped side rails. The rectangular shape of side rail was chosen to add beaming strength with rigidity, to provide sections having suitable depth and stiffness at critical locations, and to provide desirable side-wall surface area for mounting body brackets.

The new frame design called for each right-hand and left-hand side rail to be made of a front, center, and rear section (Fig. 2). Due to strength, rigidity, and minimum weight requirements and consideration given to such items as body design and rear-axle clearance requirements, it was not possible to design the side rail to be of constant depth and width and perfectly straight throughout its length.

The design specifications called for the side rail's front section to be approximately 101 in. in length, prior to bending at the forward and rear ends. For a length of 15¼ in. at the front section's forward end, the width and depth dimensions were 2.88 in. by 5.62 in. This rectangular section then tapered to a width and depth of 4.00 in. by 4.50 in.

for the remainder of the section's length. The rectangular dimensions at the forward end were necessary in order to provide a strong section at the location where the bending moment on the frame would be greatest. The rear section, having a constant width and depth of 2.75 in. by 3.50 in. throughout its 51 in. length, would require two bends at the forward end to provide a "kick up" for clearance over the rear axle. The center section, 13 in. in length, was designed to form a smooth transition between the front and rear sections. The wall thickness of the side rail throughout its length was to be 0.090 in.

The methods decided upon for manufacturing the rectangularly shaped frame side rails were somewhat a departure from the conventional methods then being used. The usual practice for fabricating a rectangularly shaped side rail consisted of using two channels, one overlapping the other, and welding the channels longitudinally along the joints by the submerged arc welding process. The average welding speed for such an operation approximated from 60 in. to 70 in. per minute.

The proposed method, in general, for manufacturing the frame side rail called for the front and rear sections of the rail to be fabricated from a circular tube which, in its final form, would be rectangular in shape. The tube would be formed in a tube mill from a flat strip of steel having the required width and thickness, and the butt seam formed would be welded by the resistance seam welding process. The tube would then be drawn through forming rolls which would produce a rectangular section having the desired dimensions. The maximum speed for this method of forming the side rails was calculated to be in the vicinity of 150 ft. per minute. It was planned to fabricate the center section from two pressed-metal stampings welded together by the submerged arc welding process.

A tremendous amount of planning, experimental processing, testing, and finalizing of details was necessary in order to bring about the proposed method for manufacturing the frame side rails. Space does not allow a detailed coverage of every phase of the manufacturing development program. The experimental processing, for example, required to perfect each individual step in the manufacturing process was a major project and would require a separate paper in itself.

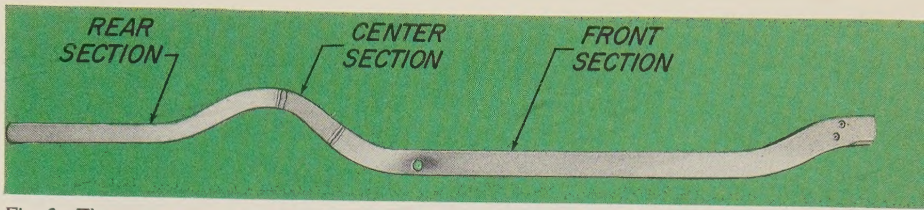


Fig. 2—The rectangular side rails of the 1955 Chevrolet passenger car frame are composed of three individual sections resistance flash welded together.

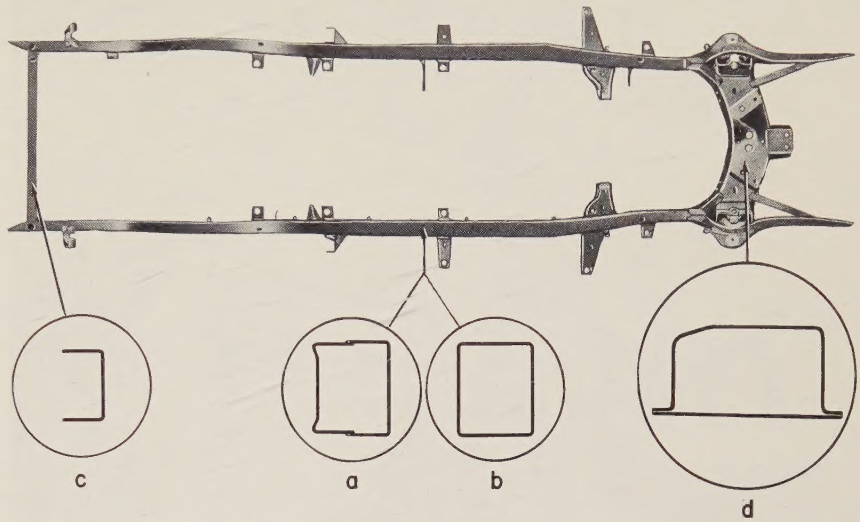


Fig. 3—The manufacturing methods used to produce the 1955 Chevrolet passenger car rectangular frame side rails were a departure from conventional methods. The conventional method for producing a rectangular rail consisted of using two overlapping channels which were joined by submerged arc welding (**a**). The method now used consists of first forming a circular tube in a tube mill. This tube is then resistance seam welded and passed through a "turks head" where a rectangular rail of the desired dimensions is produced (**b**). The frame's rear and front cross members (**c** and **d**) are manually arc welded to the side rails.

Fig. 3 shows a plan view of the 1955 Chevrolet passenger car frame, the cross section design of the front and rear cross members, and a cross sectional view of the frame side rails as produced by the conventional method of using two overlapping channels and by the method of using a circular tube. The discussion which follows will describe the unique manufacturing processes used to produce the rectangular side rail from a circular tube and some of the major problems encountered and their solution in the development of the manufacturing methods.

Frame Side Rail Manufacturing Operations

The primary objective in regard to planning the manufacturing operations was to determine the most practical approach to produce a frame side rail of rectangular section with the minimum of expensive tooling. Many changes were anticipated during the early stages of experimental processing and production, and it was necessary that simplicity of tooling be maintained so that any changes which might be required could be made with a minimum amount of delay and expense.

The overall plan for producing the side rail's rectangular front and rear sections to desired size and shape was based upon the following sequence of manufacturing operations:

- tube mill operation
- resistance seam welding operation
- rectangular transforming operation
- cut-off operation
- side rail front section transformation operation
- side rail front and rear section bending operations.

Tube Mill Operation

The major problem in the tube mill operation was to design tooling in the form of sizing roll equipment which could be mounted in two standard-type tube mills. Each tube mill would produce a tube of given diameter, to be

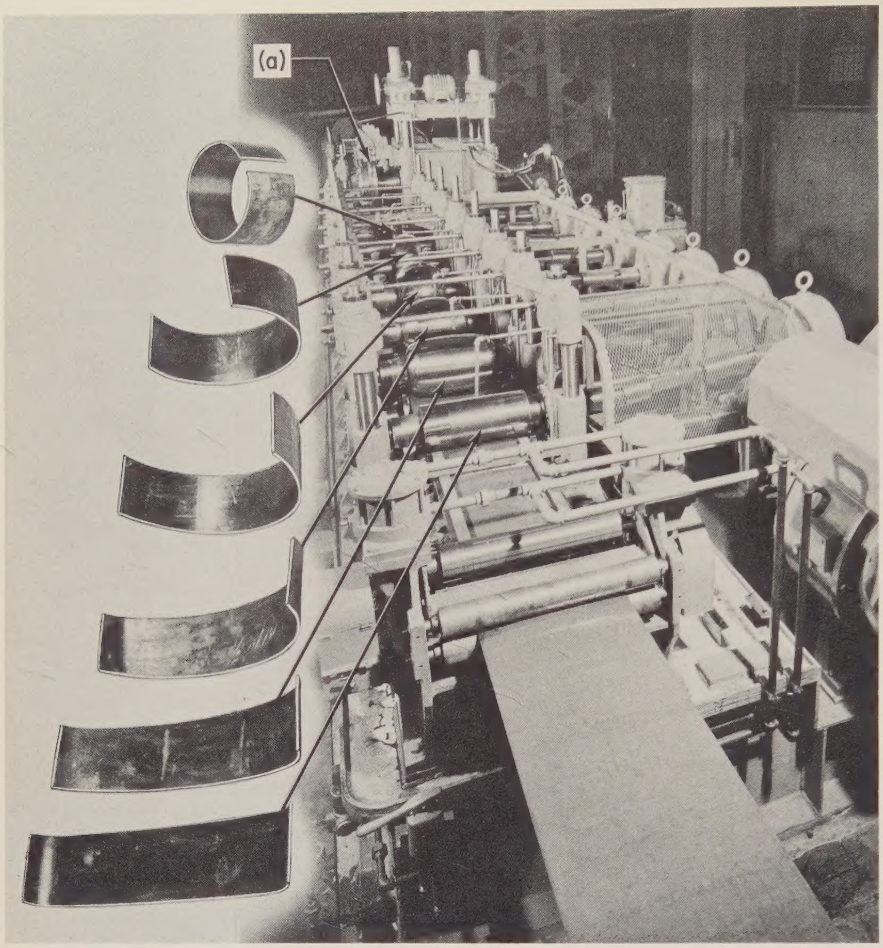
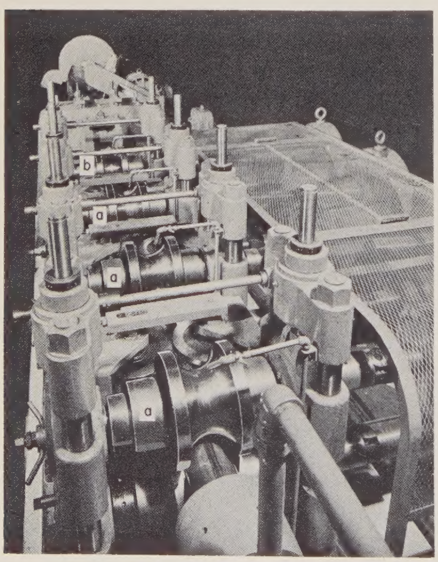


Fig. 4—The first step in producing rectangular frame side rails consists of passing a flat strip of steel through six sizing roll stations, mounted in a standard-type tube mill, to produce a circular tube of specific diameter. The tube, after leaving the last sizing roll, passes directly to the resistance seam welding station (**a**). The inset shows the transformation which takes place in the strip steel as it progresses through each sizing roll.



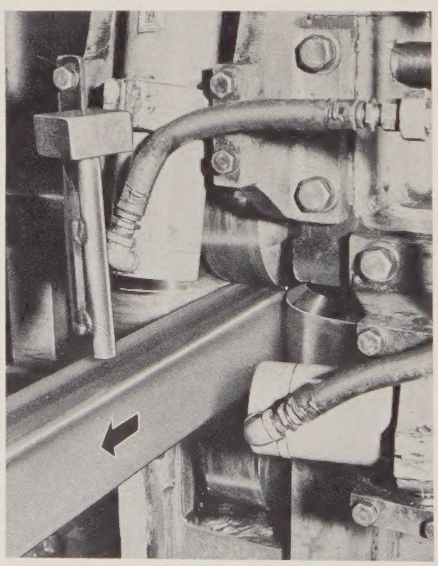


Fig. 5—After the circular tube leaves the resistance seam welding station, it passes through a series of four sizing rolls (**a** and **b** left) before entering the turks head where it is transformed from a circular to rectangular section having the desired side rail dimensions (right). Sizing rolls (**a**) maintain the tube's circular form while sizing roll (**b**) is used to augment the two sets of sizing rolls in the turks head and allow for a gradual breakdown of the tube from the circular to the rectangular section.

used for the front section and rear section of the side rail, from a flat strip of steel. It was necessary that the diameter of the tube produced by each mill be accurate in order that a rectangular section of 4.00 in. by 4.50 in. for the front section and 2.75 in. by 3.50 in. for the rear section would be obtained after the round tube was passed through the forming rolls required to transform the tube from the round to the rectangular section.

There were three points of major concern which had to be worked out by experimental processing before actual production could take place: (a) the number of passes required in the sizing roll equipment necessary to achieve a circular tube prior to the welding operation, (b) the width of flat strip steel required to produce a tube having the desired diameter and thickness, and (c) the amount of metal to allow for "burn off" during the resistance seam welding operation. It was realized that calculations for determining the width of the steel strip vary with the design of the sizing roll equipment. Some sizing roll designs stretch the material while other designs have a tendency to upset or thicken the material.

After all design details had been finalized sizing roll equipment consisting of six passes or stations, from the entrance pass to the final pass before welding, were mounted in the two standard tube mills (Fig. 4). Experimental runs were made on short lengths of flat strip steel as it passed through the sizing rolls until the desired width to use for producing each circular tube was established.

Resistance Seam Welding Operation

After the cylindrical tube leaves the last sizing roll station in the tube mill it passes directly to the resistance seam welding station.

During the continuous welding operation, the tube is supported by guide and pressure rolls which impose sufficient pressure on each side of the tube to retain its cylindrical shape and provide for sound fusion at the junction where the welding takes place. Two rotary welding electrodes are used, one on each side of the junction, which apply a constant pressure to bring the two edges in contact and cause an upsetting of the metal at the point of the fusion. The electrodes are insulated from each other by a phenol-type plastic. The outside

flash or upset is removed by a cutting tool which is in contact with the tube at the weld point.

The amount of current required to produce the necessary heat at the point of fusion is provided by a welding transformer having an input capacity of 250 kva, an output capacity of 200 kva, and a secondary current of 58,000 amperes. The speed of the resistance welding operation which is dependent on the transformer's output, the speed of the tube's travel through the tube mill, and the tubing material thickness is in the vicinity of 150 ft per minute.

In planning the resistance seam welding operation many factors had to be considered. The pressure to be applied by the welding electrodes at the point of fusion together with the pressure applied by the guide rolls was an important factor for consideration, as the applied pressure would influence the resistance furnished by the metal tube to the flow of current through the welding electrodes. Other factors which had to be considered were the current required, determination of the metal tube's resistance, and the area of contact required between the welding electrodes and the metal tube at the point of fusion.

Rectangular Transforming Operation

The final transformation of the tube from the circular to the rectangular form takes place in a *turks head*—a unit containing rolls which can be used with any form of angularity or in any position, depending upon the final form desired.

The specified 0.090-in. wall thickness of the frame's side rail was a determining factor in planning the number of final sizing rolls required to transform the circular tube, leaving the welding station, to either the 4.00 in. by 4.50 in. or 2.75 in. by 3.50 in. rectangular section leaving the turks head. The heavier the material's thickness, the more passes would be required to give a more gradual breakdown from a round to rectangular form.

It was finally decided to employ a turks head unit containing two individual stations or passes which would impose pressure on the cylindrical tube and force it into the desired rectangular dimensions. In addition, four individual final sizing roll stations were used on the tube between the welding station and the turks head (Fig. 5). The last sizing roll station immediately before the turks head was used to augment the two rolls in the turks head to allow a more gradual transformation of the tube with less possibility of a misformed shape and also to reduce the severe abrasion of the tube (Fig. 6).

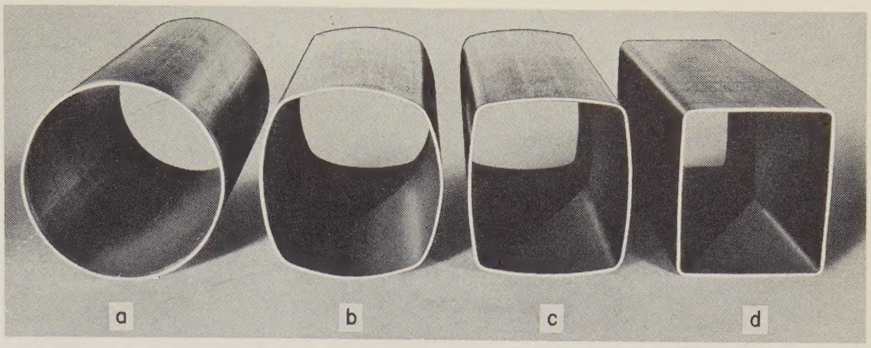


Fig. 6—A total of six sizing rolls are used to transform the tube from a circular to rectangular section. The first three sizing rolls maintain the tube's circular section **(a)** The fourth sizing roll performs a gradual breakdown of the tube's shape **(b)** before it enters the fifth sizing roll located in the turks head. This roll produces the cross section **(c)**. The final sizing roll in the turks head produces the cross section **(d)**.

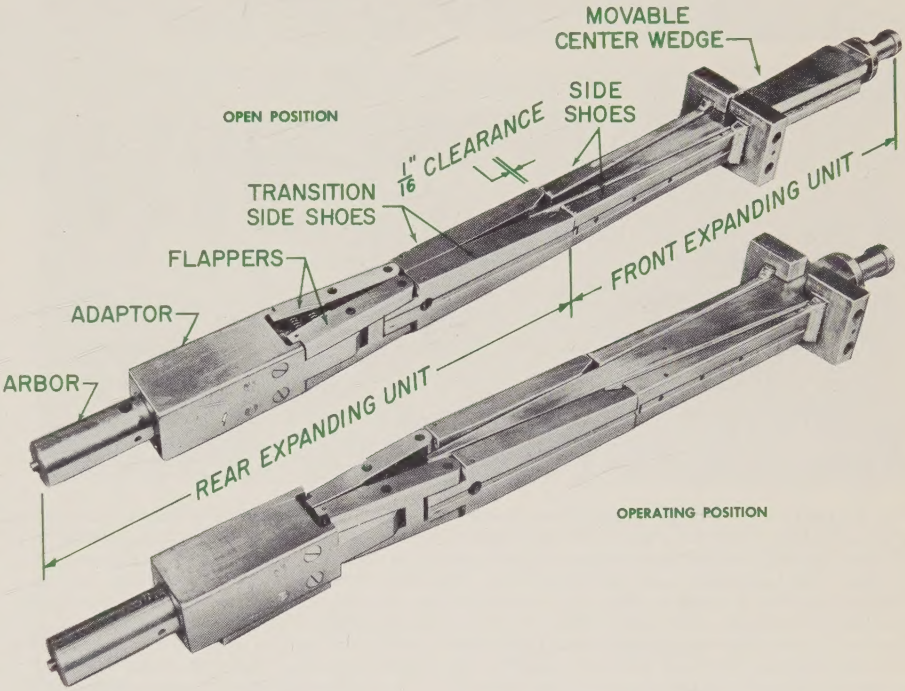


Fig. 7—The forward end of the side rail's front section is transposed from a width and depth of 4.00 in. by 4.50 in. to a width and depth of 2.88 in. by 5.62 in. by two individual expanding tools. In operation the rail is first passed over the arbor-mounted rear expanding unit which is in the open position until its forward end extends a distance of 15¼ in. beyond the transition side shoes. The front expanding unit, which also is in the open position, is then inserted into the rail until its forward end is approximately 1/16 in. from the rear expanding unit. The movable center wedge of the front expanding unit is then moved inward and forces both expanding units into the operating position. The inward movement of the center wedge achieves the desired transposition. The front expanding unit is then withdrawn and the rail stripped from the rear expanding unit.

Cut-Off Operation

The problem of how to cut the continuously moving rectangular rail emerging from the turks head to the specified lengths of 101 in. for the front section and 51 in. for the rear section was solved by utilizing a "flying saw" unit. In operation the flying saw unit clamps the moving rail, travels with it, and during the travel cuts the rail to the specified length. The rail is cut when the end of the rail hits a cut-off target which initiates the saw's cut-off stroke. The flying saw

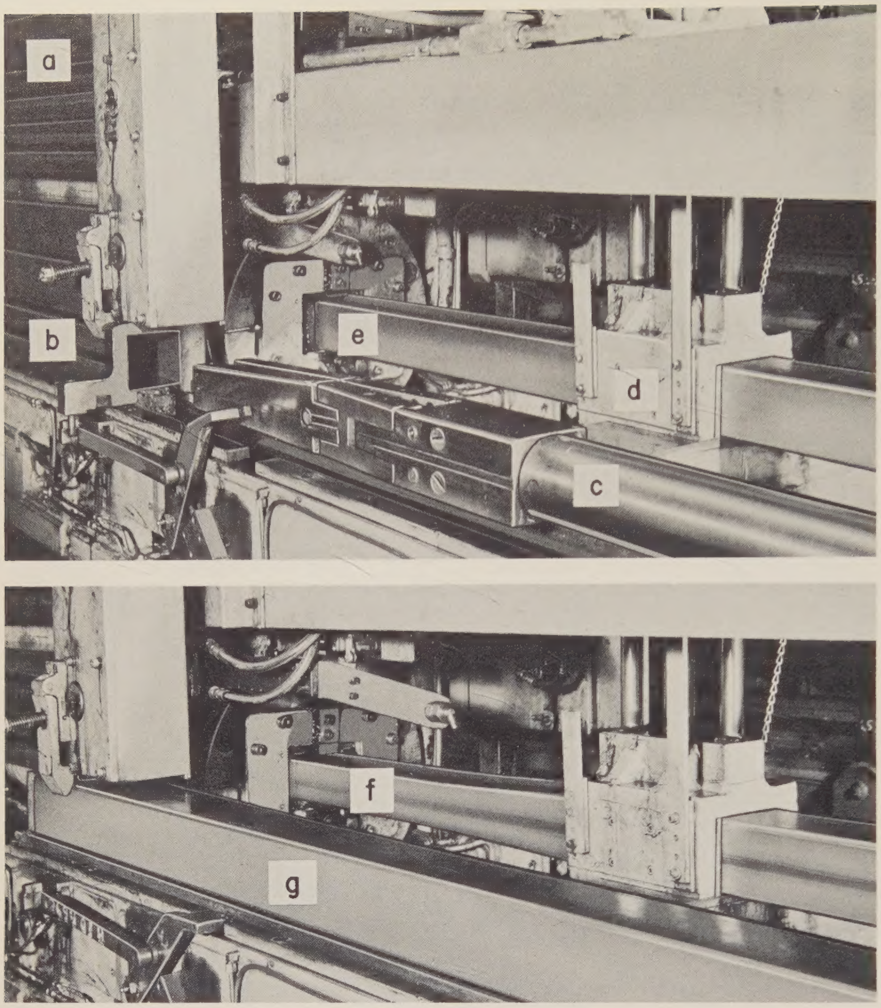


Fig. 8—The forward end of the side rail's front section requires a transposition of form from a width and depth of 4.00 in. by 4.50 in. to a width and depth of 2.88 in. by 5.62 in. The actual transposition is achieved by two individual expanding tools (Fig. 7) mounted in a specially designed hydraulically operated machine. The front section side rails are fed from the cut-off operation to two magazine-type loading stations (only one of which is visible **a**) positioned on the near and far side of the machine where they are stacked one on top of the other. While a rail to be transposed (**b**) is ready to be passed over one of the two arbor-mounted rear expanding units used (**c**) another rail, which has been passed over a rear expanding unit positioned on the far side of the machine, is moved to the central work station (**d**). The front expanding unit (not visible) then enters the rail's forward end (**e**) and performs the transposition (**f**). While the transposition is being performed, the rail on the near side of the machine has been passed over the rear expanding unit (**g**) and is ready to be moved to the central work station. After the front expanding unit has been withdrawn, the rail which has been transposed moves back to the far side of the machine where it is then stripped from the rear expanding unit.

then returns to its original position to clamp the rail again and repeat the cut-off operation.

Side-Rail Front-Section Transformation Operation

The 101-in. long side rail front section, as produced by the tube mill and forming operations, has a width and depth of 4.00 in. by 4.50 in. The design specifications call for the forward end of the front section to have a width and depth of 2.88 in. by 5.62 in. for a length of 15¼ in. This rectangular section then must taper for a length of 14³⁄₁₆ in. back to the 4.00 in. by 4.50 in. section.

Because the periphery of both the forward and rearward ends of the front section is 17 in., the problem of meeting the design specifications resolved itself into a transposition of form from the 4.00 in. by 4.50 in. section to the 2.88 in. by 5.62 in. section.

The first attempt at transposition was based on using inside expanding mandrels, which entered the rail through both the front and rear ends, in conjunction with an outside die which surrounded the total area to be transposed. Experimental processing indicated that this method was unsatisfactory because of variation in the material thickness of the rails. With a wall thickness on the heavy or maximum dimension of 0.090 in. excessive force was required to produce the desired form. It actually became a coining or reducing operation. Because of severe frictional contact between the inside mandrel and the rail, extraction of the mandrel from the rail was difficult and required an exceedingly high force to achieve separation. There also was a severe galling tendency. Because of these difficulties, it was decided to transpose the forward end of the rail without the use of an outside die.

A considerable amount of experimental processing, redesigning, and finalizing of details was necessary before a final design was achieved which was capable of performing the transposition operation efficiently and accurately and yet embodied the minimum of expensive tooling. The tooling design which was utilized for the transposition operation was based on two separate expanding tools—a front expanding unit, comprised principally of a movable center wedge and two side shoes, and an arbor-mounted rear expanding unit whose main components were two transition side shoes, two "flappers," and an adapter (Fig. 7). The front expanding unit achieves the exact transposition of the 2.88 in. by 5.62 in. section for a length of 15¼ in. The rear expanding unit facilitates the tapering of the 2.88 in. by 5.62 in. section to the 4.00 in. by 4.50 in. section.

The two expanding tools formed the

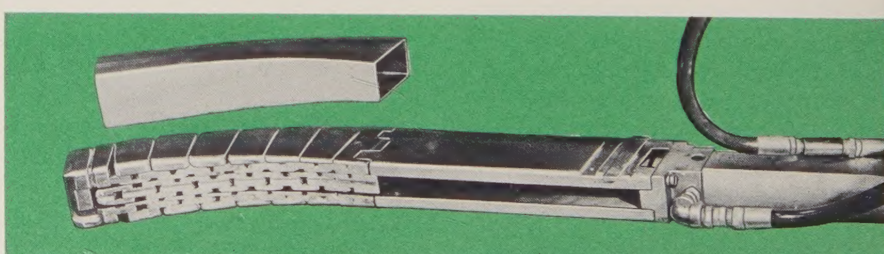


Fig. 9—The articulated mandrel used for the No. 1 bend on the side rail's front section consists of 70 individual custom-fitted, hardened and ground, chrome plated steel details.

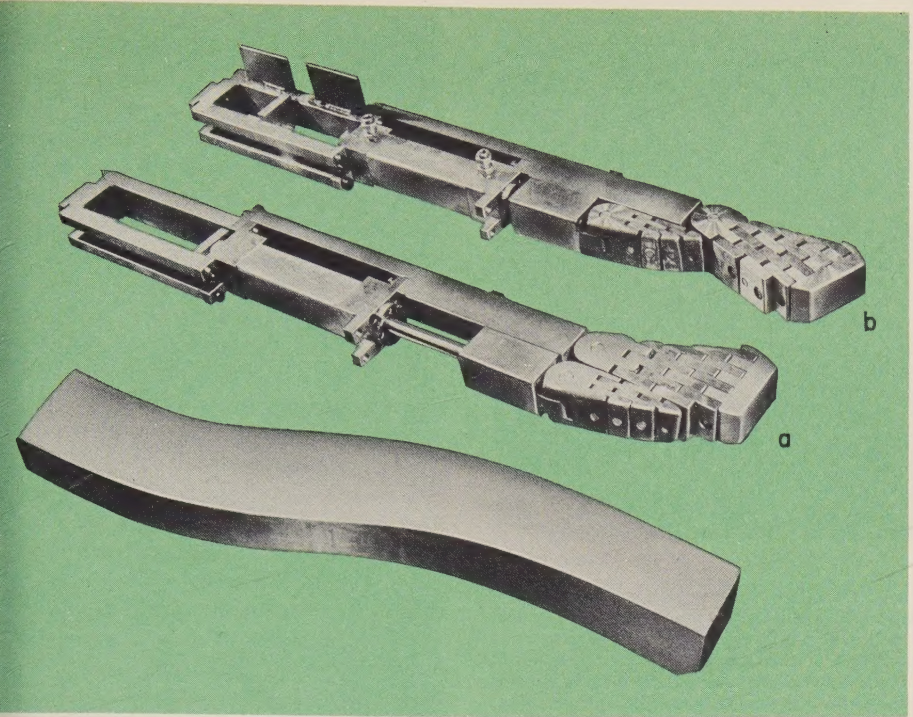


Fig. 10—The No. 3 bend on the side rail's front section is performed by an articulated mandrel referred to as a "piggy back" mandrel. Mandrel **(a)** rides on mandrel **(b)** to completely fill the inside of the rail during the bending operation.

basis about which a specially designed, hydraulically operated production machine was built to achieve the transposition operation (Fig. 8). This machine employs a shuttle-type cross feed, central work station, automatic loading and stripping of the rail from the rear expanding unit's arbor, and two fully automatic magazine-type loading stations.

Approximately 120 tons of hydraulic force is required to activate the movable center wedge of the front expanding unit from the open to the operating position. To remove the front expanding unit from the rail after transposition has taken place approximately 50 tons of force is required. This is only to start the unit's initial extraction. After approximately one-fourth in. of movement power is required only to carry the unit back to its starting point. To remove the rail from the arbor-mounted rear expanding unit approximately 50 tons of force is required for initial extraction. After a movement of approximately one-eighth in. the power required for extraction rapidly diminishes, and the rail is removed easily. This power requirement, however, varies slightly due to rail-wall thickness variation.

Side Rail Front and Rear Section Bending Operations

The most difficult frame side-rail manufacturing operation anticipated from the standpoint of design, construction, and experimental processing was the cold bending operation to be performed on the front and rear sections. The most difficult bends to perform were in the transposed area of the front section's forward end.

Bending operations are comparatively easy in a true section, that is, a section having the same width and depth throughout its length. This was the case in regard to the rear section which was of constant width and depth and required two bends. The front section, however, required a total of five bends—four in the transposed area and one at

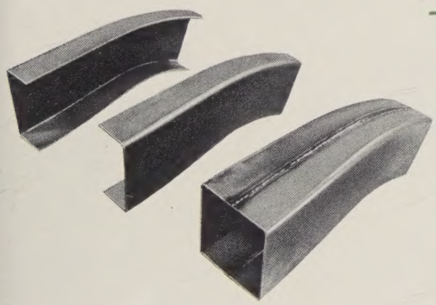


Fig. 11—The side rail's center section is fabricated from left-hand and right-hand pressed metal stampings which are submerged arc welded together.

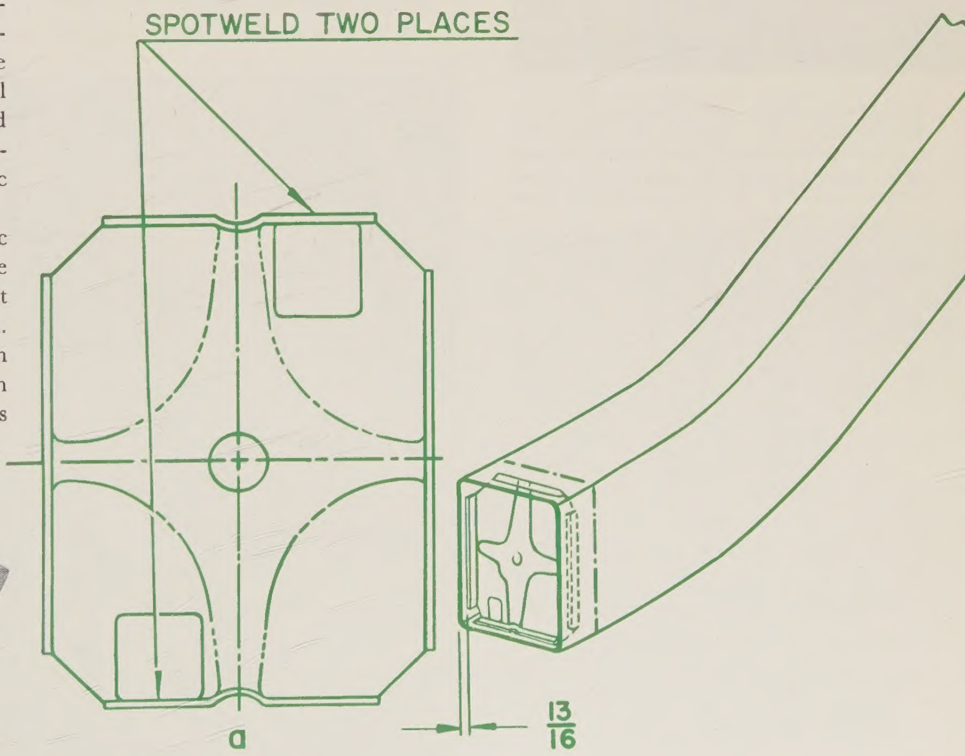


Fig. 12—A spacer **(a)** is inserted in the mating end of each front, center, and rear section of the frame side rail prior to their being resistance flash welded together to insure that the shape of each section's side walls will be retained. The spacer is inserted 13/32 of an inch from the end of each section and is spot welded in place. Shown in the upper view is a spacer as inserted in the rear end of the front section.

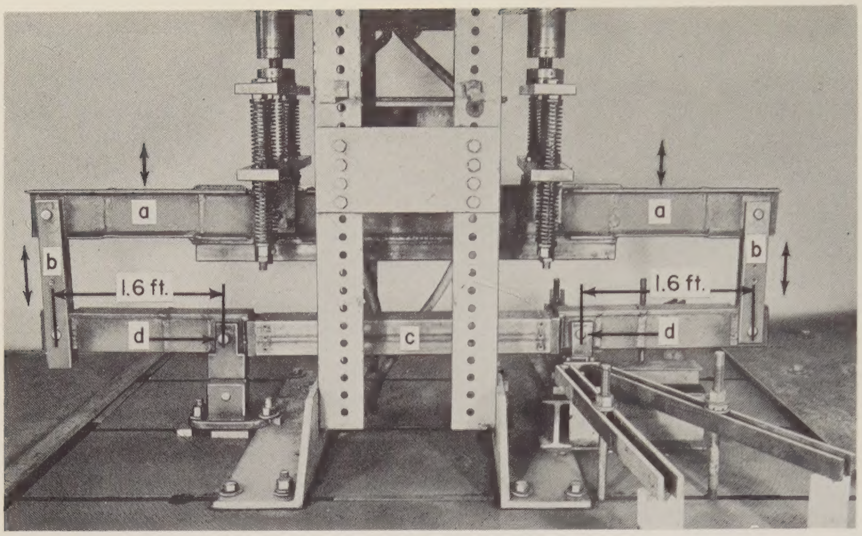


Fig. 13—A specially designed stroking machine was used to perform bending tests on the resistance seam welded side rail. A 1,300-lb up and down stroking load, applied by the beam (**a**) to each vertical link (**b**), produced a bending moment of 2,080 ft-lb which was distributed over the entire length of a 32-in. long test specimen (**c**). The vertical links were positioned at a distance of 1.6 ft from ball bearing fulcrums (**d**). The upward and downward movement of the beam caused the vertical links to move in a vertical motion which, in turn, caused the test specimen to bend upward and downward.

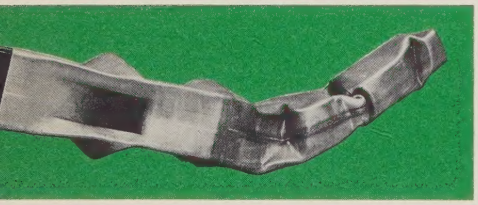


Fig. 14—Destructive tests were performed on test specimens to investigate the quality and fatigue characteristics of the side rail's resistance flash welded sections. In every case failure always occurred in the parent metal and never at the welded section.

the section's rear end. The front section's bending operations were all the more complex because no separation existed between bends in the transposed area. What actually existed was a bend on a bend. This indicated great difficulty, as whatever would be done to produce one bend would affect the next bend due to stretching and movement of the metal and the close proximity of one bend to another.

It was realized that to perform the bending operations successfully the inside area of the rail would have to be filled completely, or as close as possible, with the bending tool. It was decided to use articulated mandrels as the tooling for the bending operations.

The outside diameter of the cylindrical tube, as formed in the tube mill for both the rear and front sections, is held to close limits. The inside diameter, on the other hand, is a variable dimension due to the commercial tolerances of purchased coil-steel material. In view of this, the articulated mandrels were designed to be used with the minimum inside area and at the same time to be able to perform efficiently with the maximum inside area and to achieve bending with a minimum of wrinkling on the outside surface. Because of the varying inside dimensions of the front section, it also was necessary to design the internal articulated mandrels with a secondary articulated mandrel which was used as a wedge or expanding unit to fill the inside area completely.

Each bend on the front section's forward end required a specially designed articulated mandrel. In no case was it possible to use the same mandrel design for two different bends. This was not the case, however, with the rear section's two bends where it was possible to use the same mandrel design.

Special machinery was built with clamping dies and other suitable tooling necessary to accommodate both front and rear rail sections and also the mandrels necessary for the bending operations.

The bending operations are similar for both the front and rear sections with each bend being performed by an individual machine. In the front-section bending operation, for example, clamping dies of the bending machine are first moved to the open position. A

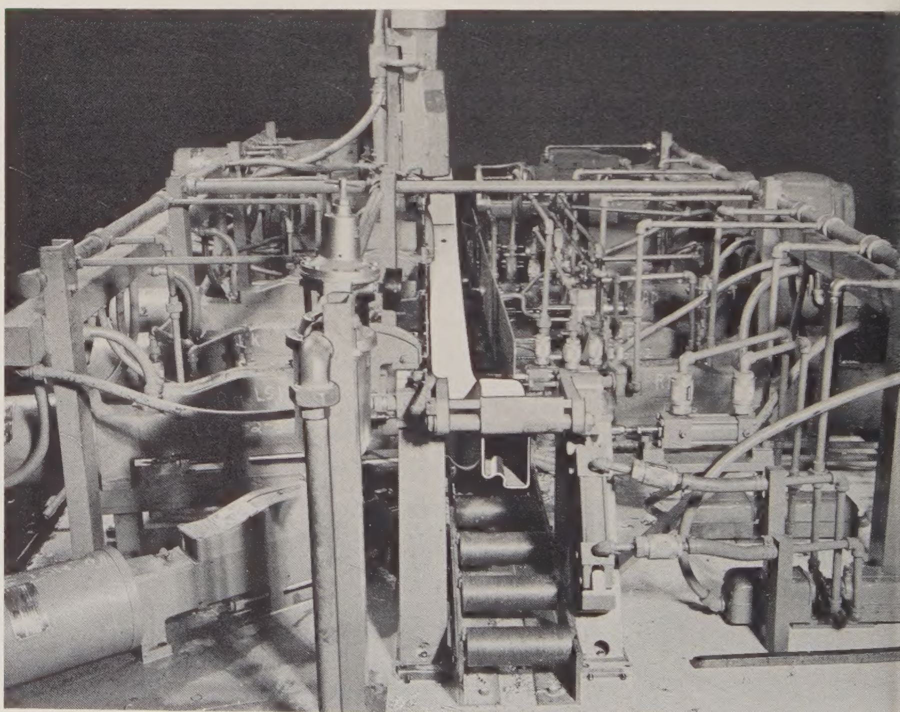


Fig. 15—The drilling of holes necessary for the attachment of clips, body brackets, and other items on each side of either a left-hand or right-hand rail is performed by an automatic, horizontal drilling machine. This is a view of a typical final set-up.

Fig. 16—Body brackets are first projection welded to the frame side rails before being manually arc welded. The projection welding machine contains special bracket holding fixtures each attached to a welding head. The rail is placed in the machine, lowered into position, and the brackets welded to the side rail in a prearranged sequence. The right-hand rail welding machine has 10 welding stations, each of which welds a bracket to the rail. The left-hand rail welding machine uses 11 welding stations. The welding stations on each projection welding machine are advanced in three separate groups and fired in four electrical sequences.

front-section side rail is inserted into the dies which are then closed to hold the rail rigid while the articulated mandrel necessary to perform the No. 1 bend is inserted into the open end of the rail (Fig. 9). The clamping dies, mandrel, and rail are then moved radially as a unit until the bending operation is complete. The clamping dies are then opened, the mandrel withdrawn, and the rail moved to the next bending machine where the No. 2 bend is performed.

The mandrel used for the No. 3 bend (Fig. 10) is referred to as a "piggy back" mandrel, as one portion rides up on another portion in order to fill the inside area of the rail as closely as possible during bending. Prior to insertion of the mandrels the inside walls of the rail are sprayed with a drawing compound.

As mentioned previously, the two bends required on the rear section were not overly difficult due to the rail having the same width and depth throughout its length. The mandrels required for bending, in turn, were not of the expanding type.

Side Rail Center Section Forming Operation

The center section of the side rail was designed to form a smooth transition between the front and rear sections. It was first decided to form the center section from a cylindrical tube in the same manner as the front and rear sections, but due to the abrupt taper required by the section's design it was not possible to expand its relatively short length to the required dimensions because of excessive stretch. It was then decided to form the center section from two pressed metal stampings, one right-hand and the other left-hand, and join the two stampings together by the submerged arc welding process (Fig. 11).

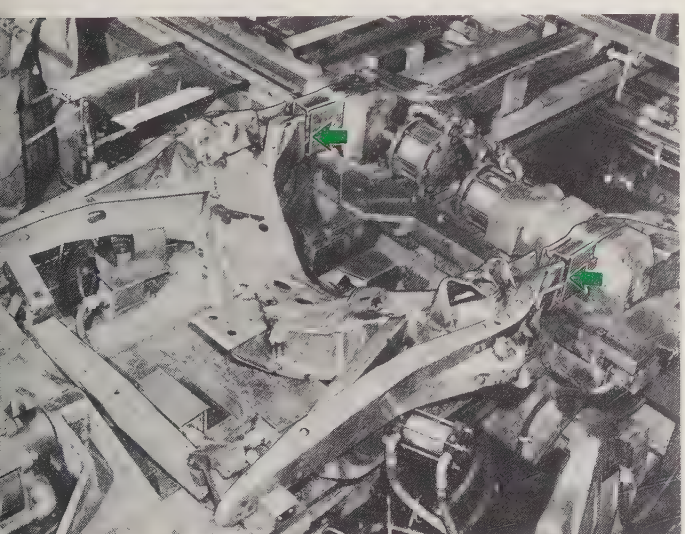
Side Rail Joining Operations

The side rail's front, center, and rear sections are joined together by resistance flash welding. Before the welding operation can take place, however, it is necessary to perform two major prewelding operations: (a) accurately size the mating ends of each section to be joined together and (b) insert a spacer in the end of each mating section.

The quality of the flash welding operation is dependent upon the accurate sizing of the mating ends. This, in turn, makes the sizing operations critical and accurate checking is required.

The spacer inserted in the end of each mating section insures that the shape of the side walls will be retained during the flash welding operation and also that the sections being joined will not move out of position or "telescope" due to stress release caused by heat from the welding operation (Fig. 12).

The resistance flash welding operation is carried out on a moving platen and a stationary platen, each of which has sufficient surface area available for the mounting of electrodes, dies, die holders, and work locators. In operation one section of the side rail is placed on the



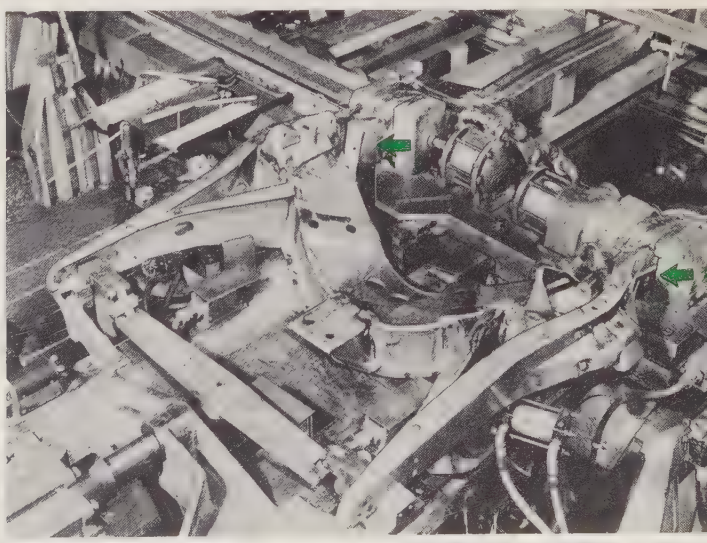


Fig. 17—The front cross member of the frame is manually arc welded to the side rails. A positioning conveyor, having fixtures which hold a left-hand and right-hand rail at the correct distance apart, automatically stops directly opposite the front cross member locating fixtures (left). The locating fixture then moves forward until the front cross member is firmly engaged in the front end of each rail, as indicated by the arrows. The front cross member is then manually arc welded to the side rails (right). The rear cross member is positioned in the same manner and manually arc welded into place.

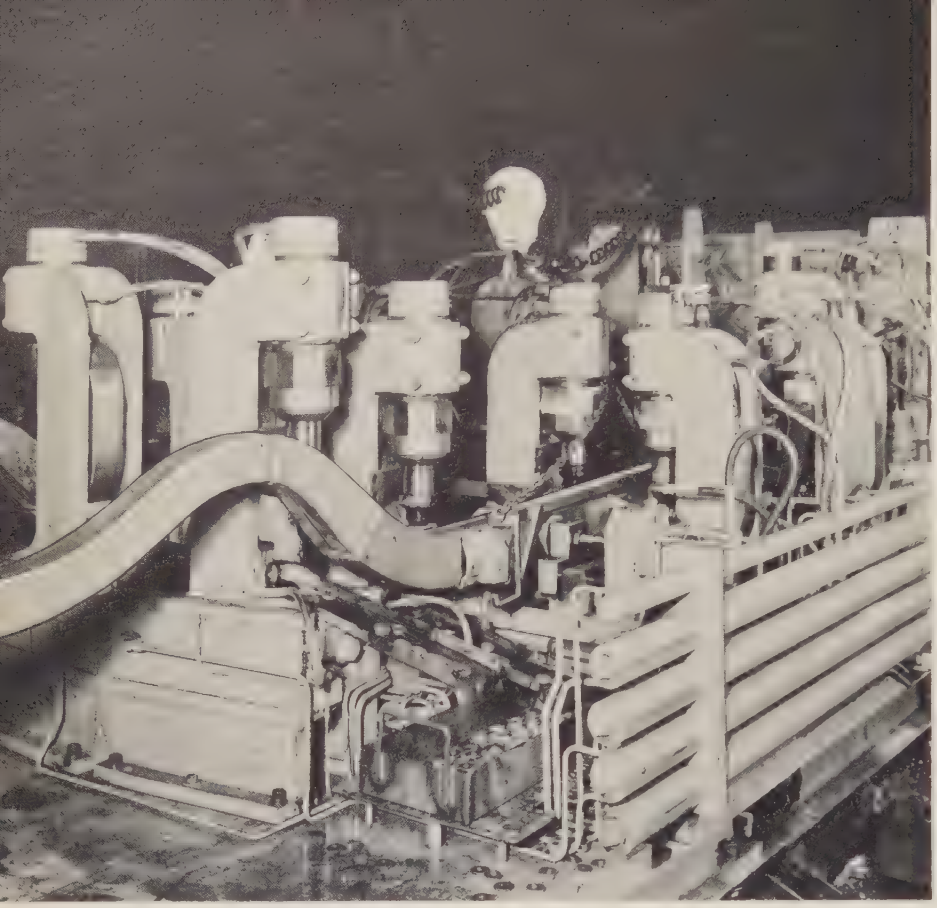


Fig. 18—All holes are pierced in body brackets at the same time by hydraulically operated "C"-type equalizing guns accurately located on a specially designed piercing fixture. The frame is rigidly mounted in locators positioned between the "C"-type guns.

stationary platen and its mating section on the moving platen. At a given time in the welding cycle, when the metal has reached the plastic state, the secondary current of the welding machine's transformer is automatically cut off or deenergized. The moving platen continues to move toward the stationary platen until the heated edges of each rail section are joined together with sufficient force to make a strong bond.

Before the individual rail sections are placed on the platens their ends are accurately sized as to rectangular shape. The amount to allow for "burn off" in the rail's length during the welding operation is taken into consideration when the rail is cut to length during the cut-off operation. The welding sequence calls for the front section to be welded first to the center section. This completed section is then welded to the rear section.

Testing of Welded Joints

Before full production of the frame side rails took place, a number of laboratory tests were conducted to determine the quality and the fatigue characteristics of the resistance seam welded side rail and the side rail's flash welded sections. Prior to performing all laboratory tests, resistance flash welding data such as flash time, upset pressure, on-time, off-time, amount of "burn off," flatness of surface at clamping area, and correct end-sizing between mating sections were recorded and checked.

A specially made stroking machine was used to perform bending tests on the resistance seam welded rails (Fig. 13). A 1,300-lb upward and downward stroking load, at a rate of 260 cycles per minute, was applied to the outer ends of two rigidly bolted extensions a distance of 1.6 ft from ball bearing fulcrums. (The rail sections were tested with the weld at the centerline of the fulcrums.) This gave a bending moment of 2,080 ft-lb which was distributed over the entire length of the rail section under test. Test results showed that when failure occurred, from 350,000 cycles upward, the failure was adjacent to the weld and approximately ½ in. to 1 in. away.

A special tensile pull-test machine also was made to check the side rail's flash welded sections. Each welded section tested was marked with the number of the welding machine on which the section was welded, the date of test, and the load at which the section under test failed. The tests indicated that the resistance flash welds were sound in that failure always occurred in the parent metal and not at the welded section. To check the quality of the welded sections, destructive tests also were made (Fig. 14).

Frame Assembly Operations

There are three major operations through which the frame side rails pass prior to their being assembled to the front and rear cross members: (a) drilling of holes in each left- and right-hand side rail, (b) projection welding of body brackets to the side rails, and (c) reinforcement of the body brackets to the side rails by manual arc welding.

Side Rail Drilling Operations

Fourteen drilled holes are required in the left-hand side rail and 18 drilled holes in the right-hand side rail to accommodate the attachment of clips, body brackets, and other items. The location of these drilled holes are on both sides of each rail.

The drilling operation is performed by automatic, horizontal drilling machines specially designed to perform the required drilling operations on either a left-hand or right-hand rail (Fig. 15).

Body Bracket Projection Welding Operation

The side rail design specifications call for 11 body brackets to be mounted on the left-hand side rail and 10 body brackets on the right-hand rail. To meet these specifications it was necessary to design projection welding machines which would separately accommodate either a left-hand or right-hand rail. Also, it was necessary to design special holding fixtures in which the various brackets would be placed prior to welding. These fixtures were to be an integral part of the welding machines and would be attached to each welding head.

Figure 16 shows an overall view of one of the projection welding machines developed after a series of experimental tests. The rail is placed in the machine and then lowered into welding position. The brackets are then welded in sequence so that all welds do not take place at the same time. The welding machine used for the right-hand rail has 10 welding

stations. A similar machine, having 11 welding stations, accommodates the left-hand rail.

Each welding station welds one bracket to the rail and the welding stations on each machine are advanced in three separate groups and fired in four electrical sequences. The staggered order of firing serves two purposes: (a) the maximum instantaneous load on any phase of the three phase power supply is limited to one 200 kva welding transformer and (b) each welding control and transformer is used on several stations thereby limiting the physical dimensions and complexity of the welding machines.

Manual Arc Welding Operation

The projection welding operation prepositions the body brackets to the side rails at the correct location. This allows the manual arc welding operation, necessary to reinforce the body brackets, to be readily accomplished. The type of weld to be performed, either fillet, tack, or puddle, is governed by design specifications.

The frame side rails progress through the various manual arc welding operations on conveyors. The operations are so arranged that a portion of the total number of inches of welding is allocated to each individual welder.

Final Assembly

The final assembly operation entails the assembly of the front and rear cross members to the right-hand and left-hand side rails.

To achieve the maximum in ease and speed of assembly a system comprised of a combination of front and rear cross member locating fixtures and a side rail positioning conveyor was developed. The locating fixtures are positioned at 90° to the conveyor. The positioning conveyor, in turn, has a number of fixtures each of which hold a left-hand side rail and a right-hand side rail at the correct distance apart and in car position.

In operation, the rails advance on the conveyor and automatically stop directly opposite the front cross member locating fixture. The locating fixture then moves forward until the front cross member firmly engages the front end of each rail (Fig. 17). The front cross member is then manually arc welded to the rails. While this operation takes place, the rear cross member also is located in its correct position on the rear end of the side rails

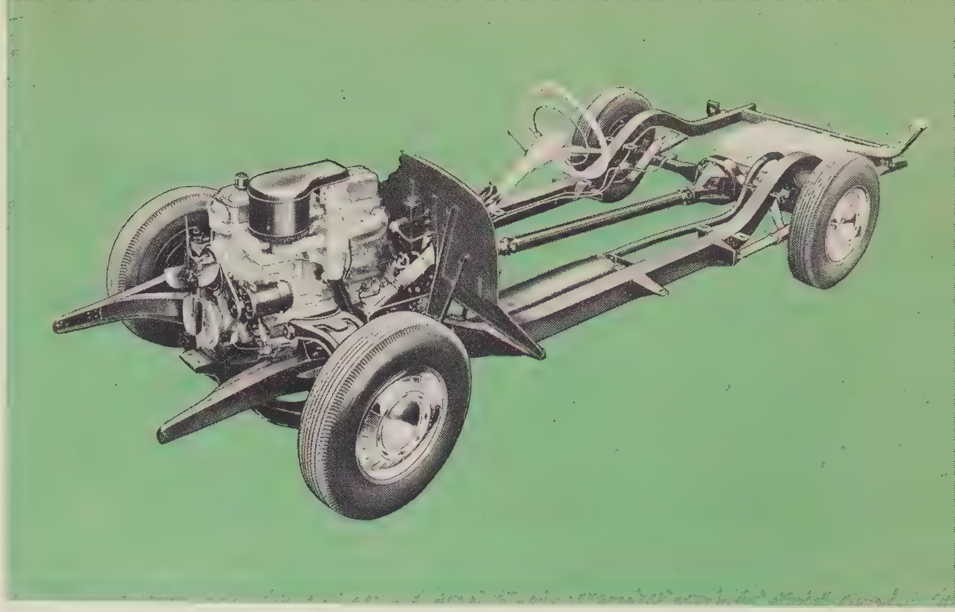


Fig. 19—The 1955 Chevrolet passenger car frame side rails provide greater resistance to torque forces than previous designs and afford an extremely rigid base for both chassis components and body.

and manually arc welded into place.

The final frame assembly is a continuous operation, with the exception of the time required to weld the front and rear cross members to the side rails.

Piercing Operation

After the frame has been assembled and all necessary welding operations performed, it passes to the final piercing operation where holes are pierced in the body brackets. Before the frame reaches the piercing fixture, however, it is first placed on a checking fixture which checks the frame for general alignment of all pertinent surfaces.

From the checking fixture the frame passes to a "walking beam" which carries the frame to a point directly over the piercing unit. The frame is then lowered into a holding fixture which is an equalizing unit incorporated into a hydraulic piercing machine. The equalizing unit assures that all frames will be held securely in the same position during the piercing operation.

The piercing machine is comprised of a number of accurately located, hydraulically operated, "C"-type equalizing guns each of which contains a punch and die mounted to a common base. The equalizing feature of each gun assures that the body bracket will not be moved out of position while being pierced.

The frame is rigidly positioned on locators mounted between the "C"-type guns (Fig. 18). This feature also acts as a checking point. If the frame does not rest fully on all locators, due to body bracket misalignment or other causes, inspection is required. All body brackets on the frame are pierced at the same time and hole dimensions are held to exceedingly close limits.

After the piercing operation has been completed, the frame moves through a special washer which contains an acid rinse to neutralize the washing solutions and produce an uncontaminated surface prior to painting. The frame is carried by a conveyor from the washer to the final flow-coat paint operation. After painting the frame is shipped to various Chevrolet passenger car assembly plants throughout the country for subsequent fulfillment of its intended function—providing support for chassis components (Fig. 19).

Summary

The new and unique manufacturing techniques used to produce the 1955 Chevrolet passenger car frame side rails presented many problems before full-scale production was realized. Each separate operation on the side rail—from tube mill to bending—required a considerable amount of planning, design, and experimental processing. The frame assembly operations likewise required considerable attention in order to assure that the manufacturing economies realized in fabricating the side rails would be retained in assembly. The experience gained from this development project is invaluable in providing a basis for working out still newer and better ways to produce passenger car frames.

A Study in the Design of Sand Molded Engine Castings

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Sand molded, gray iron castings are so extensively used in the automotive engine as to make it imperative that the engine designer give consideration to foundry problems if the most practical design of engine components is to be attained. The fact that many engine castings require the formation of interior passages, which in turn must be surrounded by other cavities, adds complications to the dry-sand coring problem. When the number and weight of dry-sand cores required to produce engine castings can be reduced, as has been accomplished on the Pontiac V-8 engine cylinder heads and cylinder block, economies can be effected. The manner in which dry-sand cores are made in quantity production is of interest to the designer because this knowledge may be helpful in designing parts which can be produced with the least hazard in the casting process. The importance of core driers in the quantity production of engine castings also should be recognized. By considering foundry problems along with functional requirements during the drawing board stages of engine components, the design engineer may aid in the eventual economical production of engine castings.

Knowledge of foundry practice aids engineers in product design

THE sand mold casting process performs an important role in the production of the automotive engine. Approximately sixty per cent of the weight of a typical passenger car engine is composed of gray iron formed by the sand molding process. Important functional engine components such as the cylinder block, cylinder heads and intake manifold, which are among the most complex castings produced in quantity in industry, are cast by this method.

The primary reason for using the sand mold casting process in the production of engine castings is that it offers a method of producing, with sufficient dimensional accuracy, the many complicated shapes and surfaces required in many engine parts. In fact, almost any shape which can be described on a drawing can be cast in metal by this method, especially if no restrictions are placed upon time and expense. Obviously, such restrictions are present in the volume production of engines. This places a responsibility upon the engine designer to employ a knowledge of foundry practice and foundry techniques to arrive at a practical engine design.

Most complications in casting design and production result either from the need for complex interior passages in the castings or from external shapes which do not permit withdrawal of the pattern from the green-sand halves of the mold. The use of dry-sand cores makes possible

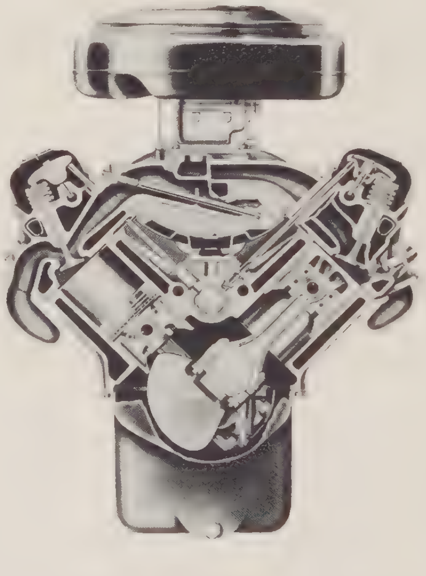


Fig. 1—A transverse section of the overhead valve, Pontiac V-8 engine reveals the many internal surfaces which must be formed in the sand mold casting process by the use of dry-sand cores. In many instances interior passages must be surrounded by other cavities to provide proper engine function. This is well illustrated in the cylinder heads, where both the intake and exhaust ports must be at least partially enveloped by water jackets to obtain cooling of the valve seats and combustion chamber areas. In the cylinder block the unfinished bores must be formed by the use of cores, which also must be surrounded by water-jacket cores. The method of setting and supporting cores such as these in the mold presents an interesting problem to the design engineer and foundryman.

the formation of such surfaces, both interior and exterior, but at the same time results in increased costs, particularly if care is not taken to keep their number and size to a minimum.

An examination of the nature of dry-sand cores reveals the reasons for the cost penalty imposed by their indiscriminate use. Dry-sand cores, sometimes called baked-sand cores, are formed by ramming a prepared mixture of core sand, cereal binder, core oil, and moisture into a core box of the required shape. The core box is then removed from the core, and, while resting on a supporting drier, the core is baked in an oven at the proper temperature for the required time. Baking solidifies the binder and thus forms a structure of the proper hardness and strength which permits handling and placement of the core in the mold.

Although the core sand might sell for 50 cents per ton at the source, the cost of the finished baked cores can grow to several cents per pound. Some of the factors which contribute to the cost of finished cores are: cost of freight, cost of core binders, compounding the core-sand mixture, labor required to form the cores, oven capacity necessary to bake the cores, and the handling and placement of cores in the mold.

While the green sand of the mold is quite readily brought back to proper strength and moisture content after use, the core sand requires more extensive reclamation procedures to regain the desired physical properties. When core sand is not reclaimed, disposal can be a problem when the foundry is located in built-up areas.

Cylinder Head Core Design

In the overhead valve engine, the cylinder head is one of the most interesting and complex castings available for

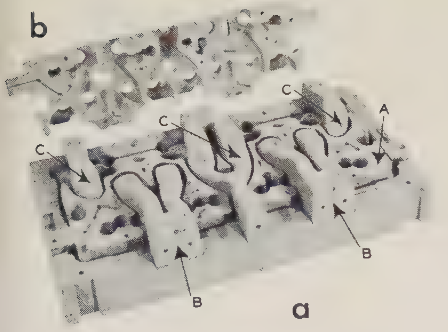


Fig. 2—The most commonly used method of coring an overhead valve engine's cylinder head requires the formation of a core assembly which is built upon a large carrier core (**a**). Upon this carrier core the other cores are set and pasted for location and support. In this view the upper half of the water-jacket core (**b**) is ready to be pasted and nailed in position to the lower half of the water-jacket core (**A**). This assembly will then require further baking to dry the paste and form a unitized water-jacket core surrounding the intake-passage (**B**) and exhaust-passage (**C**) cores.

study (Fig. 1). The engineering requirements of this part are diverse. The shape of the combustion chamber, the size and location of the valves, size and shape of the intake and exhaust passages, location of push rod holes and cylinder head bolts, provision for support of the rocker arm mechanism, and the need for water cavities to obtain cooling around the valves and spark plugs are some of the considerations involved. Furthermore, as in most design work, the need for minimum over-all size and weight confronts the designer.

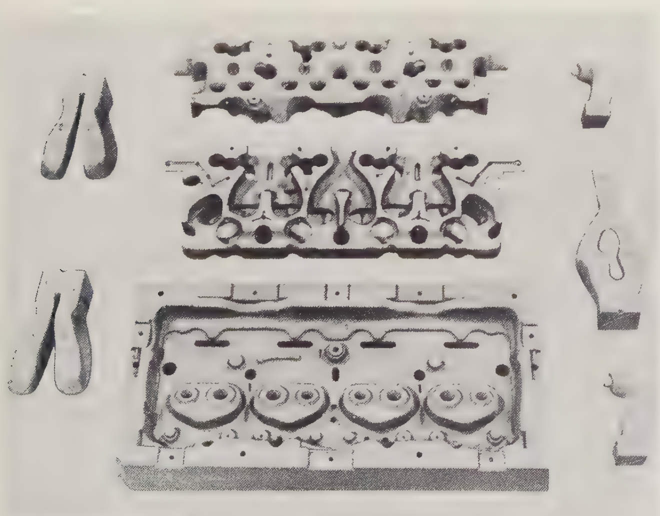
The coring of the cylinder head to meet these functional requirements illustrates a rather basic problem in casting design. Here a condition occurs in which cores must be surrounded by other cores to obtain the necessary shapes. It is evident that the intake ports are internal passages which cannot be formed by the green sand of the mold. Therefore, dry-sand cores must be used for their formation. This also applies to the exhaust ports. As shown in Fig. 1, these intake and exhaust passages must be surrounded by water passages which also must be formed in the casting process by the use of dry-sand cores.

In the conventional method of coring an overhead valve engine's cylinder head, the water jacket core is made in two pieces and is pasted and nailed together along a plane after setting of the port cores is completed (Fig. 2). The assembly is made on a large slab core, sometimes called a carrier core. A core assembly of this type requires a separate core room assembly line for production. From the core room the assembly is transported to the molding line for setting in the green-sand mold. The need for this type of pasted core assembly can result in added costs. Another possible disadvantage with this method is that surfaces which might seem to be perfectly matched and pasted, prior to the pouring of iron, sometimes distort and break apart under the effect of the hot, liquid metal. When this happens, iron flows into the void, and a fin is formed inside the casting. A fin of this nature, located in a critical area of the water jacket, can result in locally restricting the flow of cooling water and the possible development of a very hot region with accompanying distortion and depreciated engine durability.

The conventional method of coring an overhead valve engine's cylinder head was used to cast the first experimental cylinder head in the development of the Pontiac V-8 engine. Eight cores totaling 42 lb were required to cast each head. The lower slab core alone weighed 25 lb which, on the basis of two heads per engine, represented 50 lb of core sand per engine.

A casting technique was devised by Pontiac Motor Division engineers to eliminate the large carrier core upon which the other cores were set. As a result of this new method, the eight cores necessary in the conventional method have been reduced to four cores totaling 17 lb for the production cylinder head (Fig. 3). The use of four cores represents a saving of 50 lb of core sand per engine.

The four cores are set directly into the green-sand mold and are supported by core prints and small metal chaplets (Fig. 4). The small lower core called the sub-jacket core is set first followed by the intake-port cores which are made in one unit by using connected core prints to form a bar. The main body of the water-jacket core is placed in position in the mold over the sub-jacket core and intake-port cores. The contact between the two water-jacket cores is on wedge-shaped surfaces which tend to facilitate setting. The exhaust-port cores, which also are connected by common core



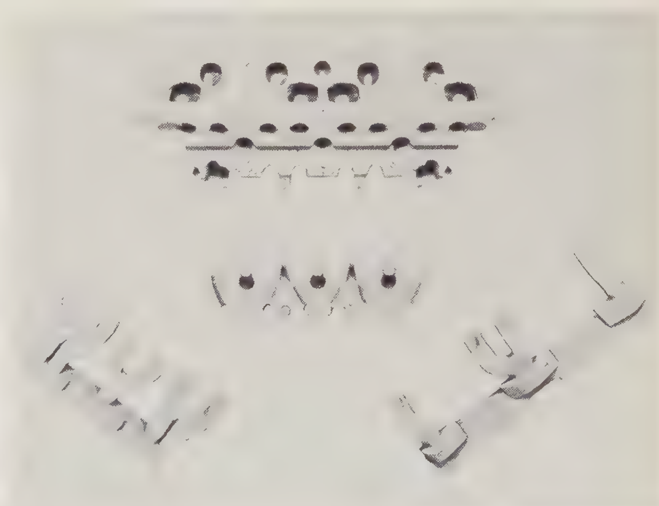


Fig. 3—Eight cores (left) were required to cast an early Pontiac engine cylinder head using the conventional coring method. Only four cores (right) are required to form the cylinder head as it is now being cast in production. No carrier core is required since the simplified coring design makes it possible to set the production cores directly into the green-sand mold. The elimination of the separate core assembly and carrier core results in a close dimensional relationship between the cores and the external surfaces formed by the mold. The cores are supported in the green-sand mold by core prints and small metal chaplets.

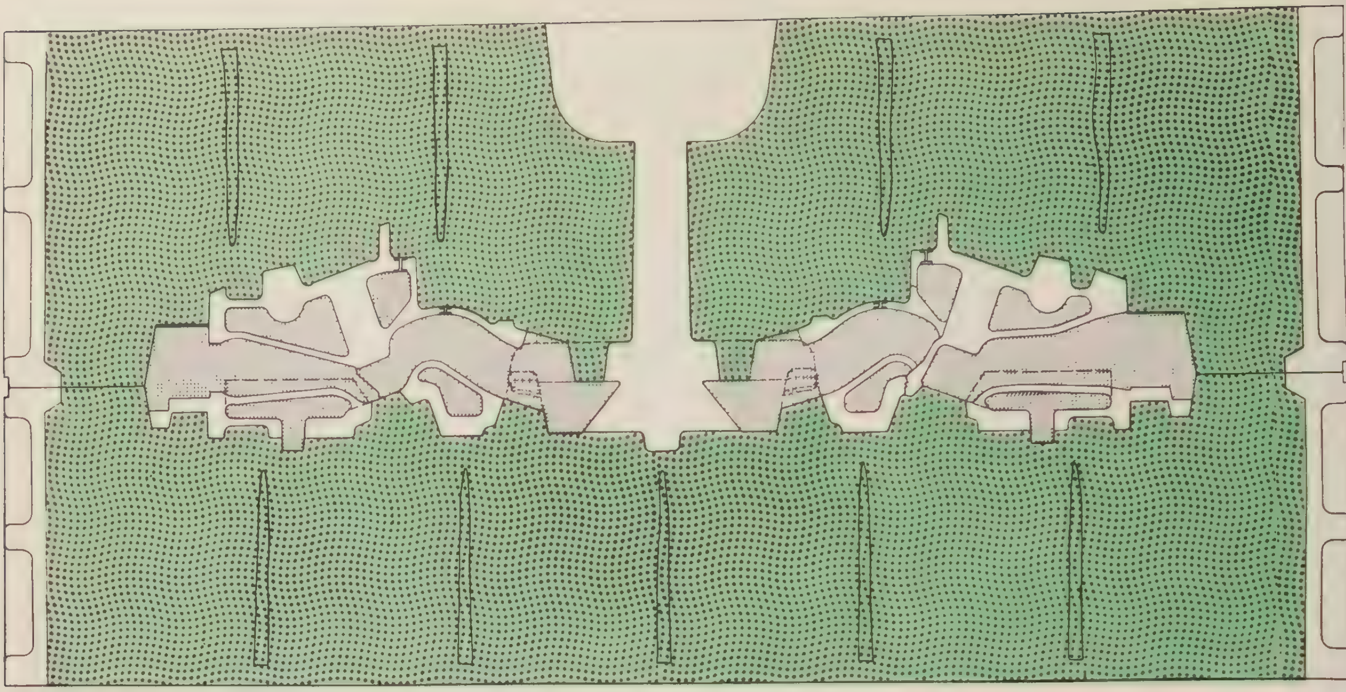


Fig. 4—A cross section through the cylinder-head mold shows that two heads are cast in each flask for economy of production. The cores are securely positioned by the use of core prints and by small metal chaplets which fuse with the hot iron. These expedients prevent the cores from floating away under the buoyant effect of the heavy liquid-metal. This buoyant force can be three times the actual weight of the cores when gray iron is being cast.

prints, are then set into the mold by sliding them through openings in the main water-jacket core (Fig. 5). These openings in the water-jacket core had to be carefully designed not only to permit their easy formation in this core itself but also to make certain that the exhaust-port cores would enter and be positioned properly.

The fact that no pasting is done at the contacting surfaces of the two jacket cores means that fins occur in the finished castings at these surfaces. Such fins, however, are always present in every casting, but they are located so as not to harm valve seat cooling. No fins can occur in the critical area between the intake and exhaust valves, and a free, unobstructed flow of coolant from holes in the water delivery tube is always assured. Consistency of cooling also is promoted by drilling through the fins from the bottom of the head in several places. Because of this positive fin formation due to the elimination of pasting and nailing, the production castings have been found to exhibit the same temperature balance characteristics as their experimental predecessors.

Cylinder Block Core Design

The cylinder block of the overhead valve V-8 engine probably has only slightly fewer engineering functions than do the cylinder heads. Due to its size, however, it does require more cores and a greater amount of core sand for its formation.

Eighteen cores were required to cast the cylinder block for the first experimental overhead valve engine produced by Pontiac Motor (Fig. 6 left). This block was cast in a conventional manner and represents, in general, the method used by many V-8 engine producers. Three of the 18 cores were required because the clutch housing was cast as an integral unit with the block. In contrast, only eight cores are required to cast the present production block (Fig. 6 right). These cores weigh 124 lb, whereas the cores made by the conventional coring method for the experimental engine weighed 236 lb.

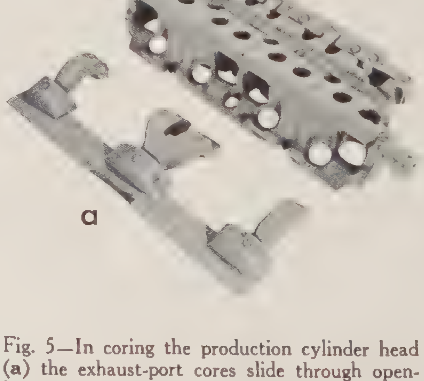
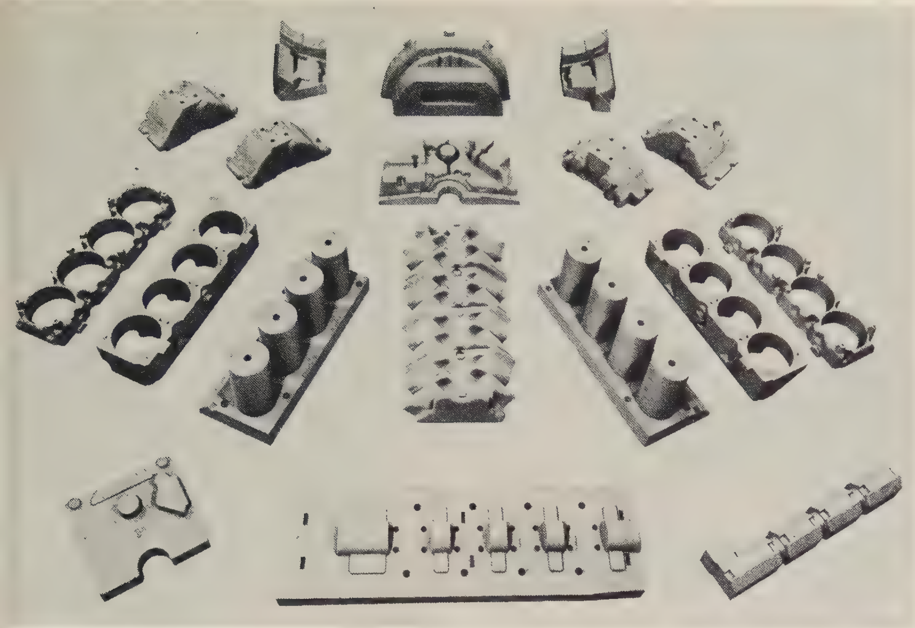


Fig. 5—In coring the production cylinder head (**a**) the exhaust-port cores slide through openings in the water-jacket core (**b**). This operation takes place on the molding line.

As in the case of the cylinder head, casting simplification for the cylinder block was achieved fundamentally by a design which permitted the elimination of core assemblies. Three core assemblies are required in the conventional coring method, and the block is cast in the upside-down position.

The method developed to cast the production V-8 block is almost self-explanatory. Fig. 7 shows a transverse cross section through the cylinder-block mold and indicates that the block is cast in the upright position. Each pair of cylinder-barrel cores is an integral part of the crankcase core. The camshaft area is formed by the combination crankcase and barrel core. The water-jacket core for each bank of cylinders is of one-piece design to eliminate the formation of fins in the water jackets. These water-jacket cores print into the drag side of the mold and are given additional support by chaplets in the drag. The water-jacket cores are prevented from floating away by the use of chaplets on the cope side.

The entire top of the cylinder block is formed by the green sand of the mold. This is made possible by eliminating projecting flanges in the center area. It was possible to eliminate the need for



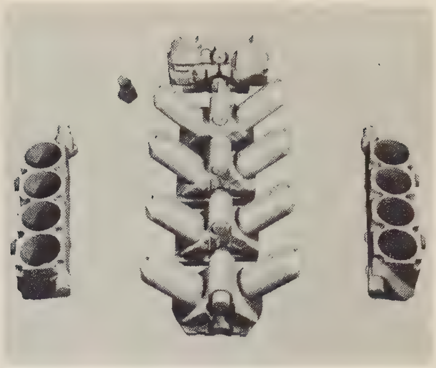


Fig. 6—Another example of reduction in both the number and weight of cores is shown by this comparison of the 18 cores (left) required to cast the first Pontiac experimental overhead-valve cylinder block and the 8 cores (above) required to cast the production cylinder block. As was the case with the cylinder heads, separate core assemblies have been eliminated, and the cores are set directly in the green-sand mold. The production casting method eliminates 10 cores weighing 112 lb.

such flanges and, in turn, the need for a core in this area by sealing the engine-top cover on the lower edges of the heads and at the ends on the curved surface of the block.

Fig. 8 shows a longitudinal section through the cylinder-block mold and indicates other details of the casting method. Only one dry-sand core, at the rear of the block, is needed to form any external surface. This core is set separately into the mold while the others are first assembled in a loading fixture. A setting fixture on the molding line then lifts this group of cores and places them in position in the mold.

Intake Manifold Core Design

The intake manifold of the Pontiac V-8 engine requires seven cores for its formation. One of these is required to form the water connecting passage at the front of the manifold. In this case an assembly of cores is used and is made up on a fixture (Fig. 9). The two side supporting cores are first set in the fixture. The runner cores, exhaust surge-heat passage core, and the water-manifold core are then pasted to these supporting cores in the upside-down position. This method of forming the core assembly on the two side-rail cores in the fixture eliminates the need for a large carrier core which would otherwise extend the complete width and length of the manifold. Obviously, the two side-rail cores can be formed easier, baked quicker, and produced at less cost than could the large core otherwise required.

Volume Core Production

An analysis of the Pontiac V-8 engine castings reveals that approximately 31 cores are required to produce the castings for one complete engine. If the production rate is 2,500 engines per day, 77,500 cores have to be made daily to meet production, since cores perform their intended function only once.

To speed production of dry-sand cores automatic core blowing machines are used. A cross section through one of these machines shows the cylinder block water-jacket core after blowing has been completed (Fig. 10). During actual blowing of the sand the main body of the core box is in the "up" position where it fits the box cover. The sand is blown through holes in a blow plate which carries this core-box cover. After the core box is filled with sand, it is lowered to a predetermined position and a core drier is placed on the top side (Fig. 11). The assembly is then turned over, and the

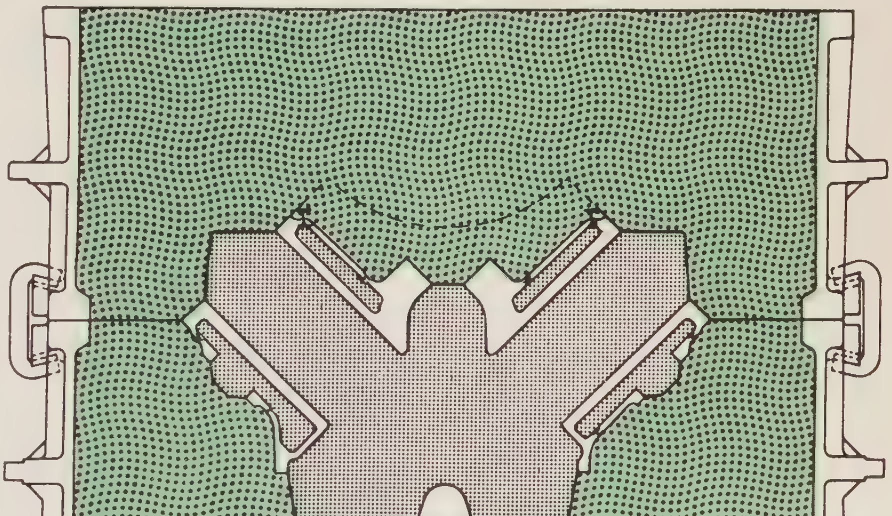


Fig. 7—A transverse cross section through the production cylinder-block mold shows the relative position of the cores. The cylinder-barrel cores are integral with the crankcase cores, as is the core used to form the camshaft area.

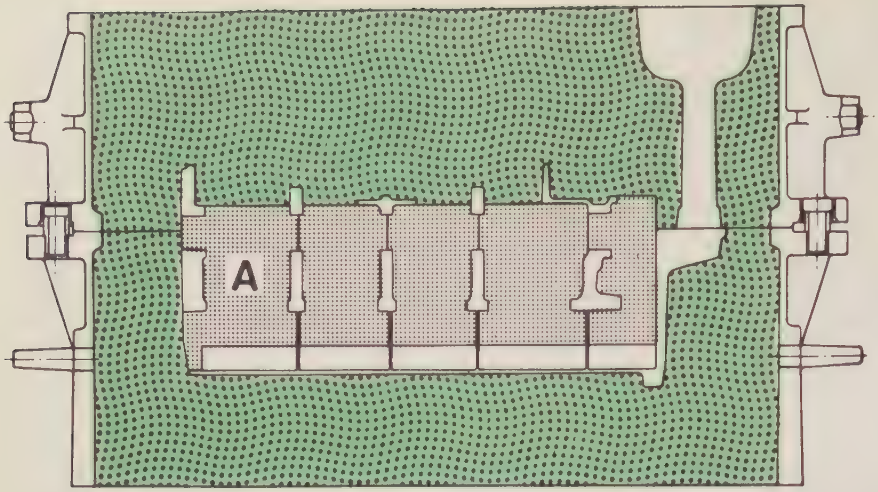


Fig. 8—A longitudinal section through the production cylinder-block mold shows that only one core (**A**), at the rear of the block, is needed to form any external surface. This surface could not be formed by the green sand because the pattern would have back-draft and could not be removed from the drag half of the mold.

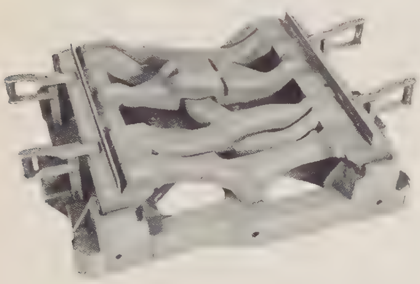


Fig. 9—The intake manifold core assembly is formed on a fixture. The runner cores are pasted to two side-rail cores, and the complete assembly is baked to dry the paste and form a unit strong enough to handle and place in the mold.

core box is removed, leaving the core resting on the drier. (The *core drier* is actually a form of tray which furnishes support for the sand in the unbaked condition and prevents sagging or distortion.) The drier with the core then goes to the oven. The core drier must accompany the core through the entire baking period, which is as long as 150 minutes for some cores. While only one core box might be required to form 360 cores per hour on the latest type of rotary core blower, 1,000 core driers might be required to dry these cores.

Core driers are usually annealed aluminum alloy castings (Fig. 12). The simplest form of drier, and consequently the cheapest, is the flat-plate type. The slab core used at the rear of the cylinder block is dried on this type. Sometimes it is necessary to support very complex surfaces with a specially designed drier. This condition is avoided whenever possible for economic reasons.

Core driers must be considered when a change is contemplated on a production casting. While it might be relatively easy to make changes on a few patterns or core boxes, the changes on the large number of core driers used in production would not be insignificant. Sometimes even a relatively minor change on a bulkhead wall or the enlargement of the cylinder bore requires a completely new set of driers and can thereby make a seemingly simple change quite costly.

In the design of any core simplicity is a major goal. Since it is necessary to remove the core box from the core before drying, the core box must have draft or taper on its sides to permit withdrawal. This means that the parting line of the core box must be considered by the designer. Back-drafted surfaces, which would require the removal of loose pieces of the core box, should be avoided if practicable. Small projections of core sand which might be broken off by the rush of the heavy iron during pouring should be avoided. Any sand broken off in this manner can lodge in a vital spot in a casting and thus scrap the piece. When this defect is not discernible until machining is near completion, even more effort and money are wasted.

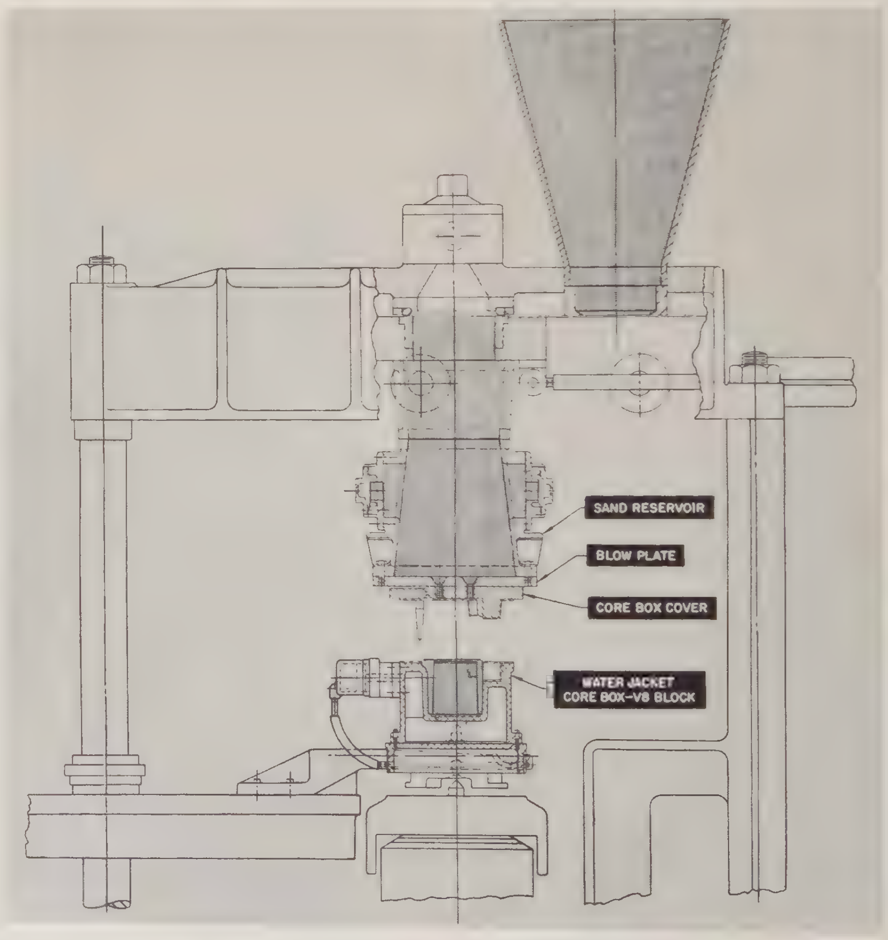


Fig. 10—Automatic core blowing machines speed the production of dry-sand cores, but their use greatly increases the number of core driers necessary to maintain production. This cross section through the blowing station of a core blower shows the core in the core box after blowing has been completed.

Fig. 11—At this five-station rotary core blower a core drier is being placed on a newly formed core prior to its baking. In the right foreground a stack of these core driers is visible. On the left are racks used to transport the cores through gas-fired ovens.

Core sections should be of such size to assure that "burning-in" does not happen. Unfortunately, the size of some critical sections looks larger on paper than when made into sand. Also, the sections of sand sometimes do not produce quite as large a cavity in the casting. In some cases cores are dipped in a refractory material to retard this so-called "burning-in." This represents extra expense and is done only when necessary to obtain a good interior surface. The use of sand with proper grain distribution can be helpful at times in producing smooth casting surfaces.

Sometimes wires are used in cores to provide reinforcement and prevent core breakage. In general, the wires used are a source of trouble and cost. In the production of the Pontiac V-8 engine no wires are required to reinforce the cores. The relatively short water-jacket cores of the overhead valve engine, as compared to an in-line engine, together with core sections of adequate size, have made this possible. The elimination of wires not only speeds up the core blowing operation but also simplifies cleaning out the casting.

The fact that foundry practice is a practical art, requiring years of study and practice by foundrymen, is borne out by the fact that numerous mixes of sand and binders are used to form the cores used in production casting. As many as eight different sand mixes have been in use at one time in the Pontiac Motor foundry. Also, the baking time varies for each core. Such properties as grain fineness, green strength, hot strength, permeability, collapsibility, and warpage tendency must be varied and controlled to produce the best possible castings.

Green Sand Cores

From this discussion of dry-sand cores and the complications they involve, it is evident that the ideal casting would require no cores. An intermediate step in this direction is sometimes possible in certain castings which require internal cavities. The clutch housing is an example (Fig. 13).

The internal surface of the clutch housing must be formed by a core. In this case a green-sand core is used; that is, the core is unbaked and is made from the same green sand used for the mold formation. Because green-sand cores cannot be handled, they are made on the molding line. They must be machine-set into the drag. This insures accurate location in the mold and the formation of accurate castings.

In the case of the clutch housing, green-sand cores are used only when ample "printing" or supporting surfaces are available for the core. In most instances the substitution of a green-sand core for a dry-sand core is a step toward cost reduction.

Miscellaneous Design Considerations

The accuracy of the core setting operation and the amount of core shift which

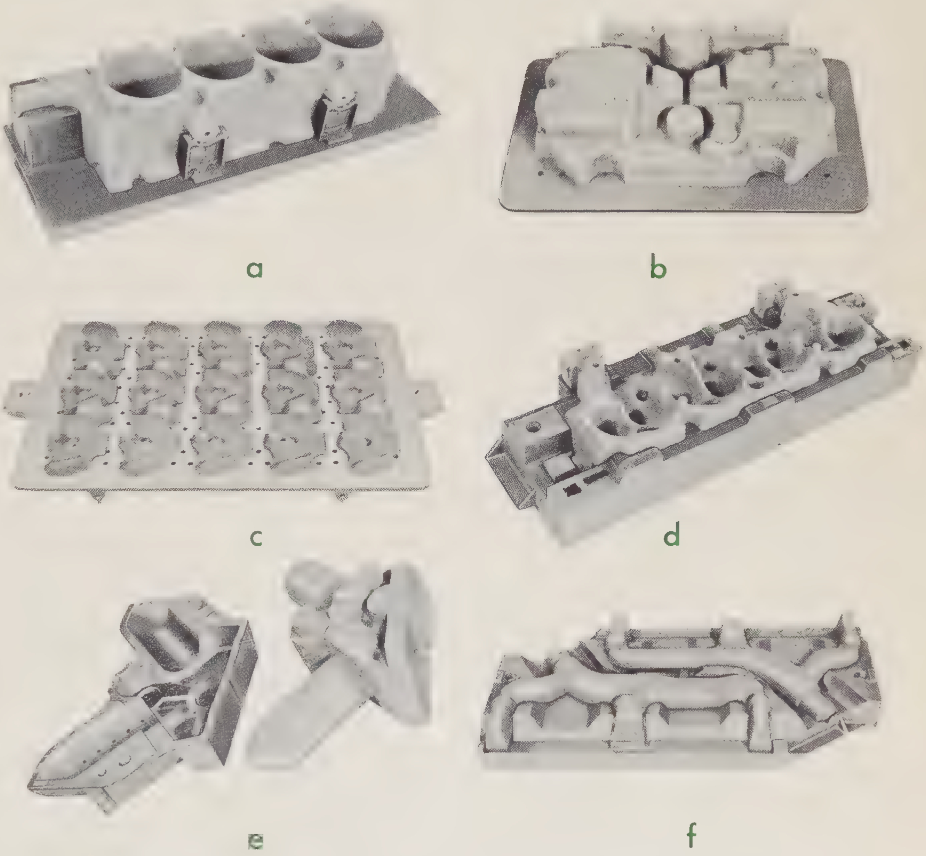


Fig. 12—The cylinder block water-jacket core is baked on a flat-plate core drier with necessary projections to support overhanging core prints (**a**). A flat-plate core drier is used to bake the slab core which forms the rear of the cylinder block (**b**). Five sub-jacket, cylinder-head cores are dried on a single flat-plate core drier (**c**). The main water-jacket core of the cylinder head requires a specially designed core drier to support its complex surfaces (**d**). The combination crankcase and cylinder barrel core also requires a specially designed core drier (**e**). Two exhaust-manifold cores are dried simultaneously on a common drier (**f**). Most core driers have holes in their lower surfaces to aid in the convection of heat to the cores.

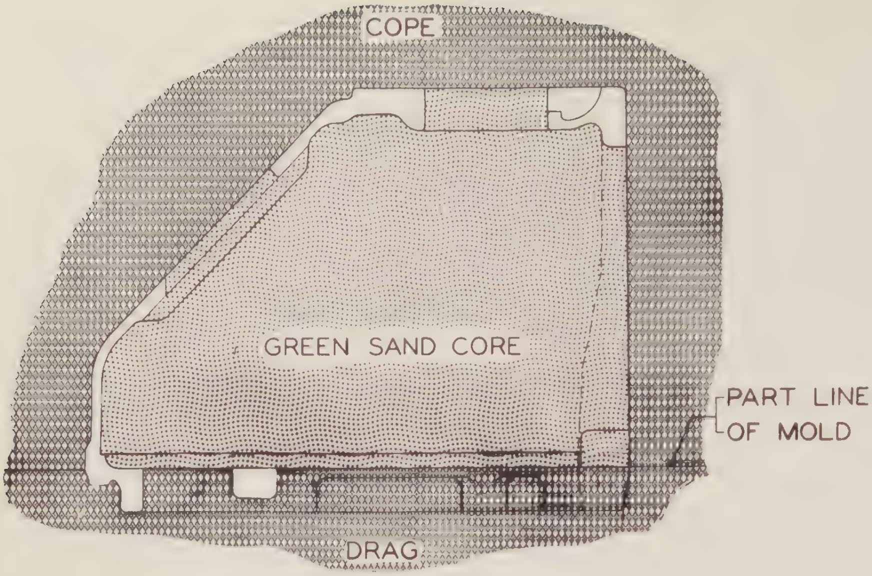


Fig. 13—The interior surface of the clutch housing is usually formed by the use of a green-sand core. The core is made from the same green sand used for mold formation. The two types of cross hatching distinguish the green-sand core from the green sand of the cope and drag.

develops during handling of the mold or during pouring have a direct influence on a casting's wall thickness which can safely be specified for a given part. The design engineer naturally wants most casting walls to be as thin as possible in order to keep weight to a minimum. However, realism requires a recognition of the fact that only certain minimums can be reached in the wall thicknesses of mass-produced, sand-molded castings. While most drawings of engine parts call for either 0.180 in. or 0.200 in. wall thicknesses, in some cases a 0.160 in. thickness is specified for a small part, while up to 0.240 in. may be specified for heavily loaded members of some castings.

In engine casting design the usual precautions for avoiding heavy sections adjacent to light sections should be observed. In fact, the more nearly uniform the sections are throughout the casting, the more evenly the iron cools and solidifies, thereby reducing the possibility of forming excessive cooling stresses. Care also should be taken to break up flat walls with ribs or adjoining walls to assure proper feeding during cooling.

The size of the flask required for a casting can be a consideration in cost control. Flask size determines the amount of green sand which must be handled. For a high-production foundry the cost of preparing, handling, and reclaiming green sand can be appreciable. While the size of the flask is not a direct concern of the product engineer, it sometimes becomes a factor to be considered when a projection of questionable value would obviously require the use of a larger flask.

In the design of engine castings the machinability of the parts also should be considered. In all cases drilled holes should be far enough from vertical walls to assure a clean break-through of the drill and thereby keep drill breakage to a minimum. The increased use of broaching to machine exterior surfaces can be another source of trouble. Bosses or sections of iron which might be sufficiently strong to perform their intended function satisfactorily might not be strong enough to withstand the higher loads of a broaching operation. Lack of casting accuracy, resulting in an excessive amount of metal to be removed, also can produce difficulties of this nature.

Another important consideration in casting design, although somewhat subjective, is the appearance of the castings. Opinions vary concerning beauty—if such a word can properly be applied to cast iron—but, in general, the casting that has a functional appearance is one that will have a better chance of performing its intended function satisfactorily. Smooth blending of surfaces promotes the easy flow of metal through the mold during pouring and also promotes feeding from the sprue during solidification. Other design principles which fall into this category are the avoidance of isolated external projections which might break off during handling and the use of fillets large enough to avoid excessive stress concentration under load.

Probably no study of engine castings should neglect mention of the physical properties of gray cast iron. Its relatively low melting point (about 2,200° F), its fluidity, and its comparatively low shrinkage during solidification contribute to its castability. Its comparative cheapness is another advantage. Gray cast iron is considered to be very machinable if it is properly cooled. Its distribution of free carbon in flake form, which produces its gray appearance, also imparts low sliding friction qualities and, in addition, gives it good vibration dampening capacity. This combination of properties is difficult to find in other metals.

Summary

Sand mold casting offers a fundamentally economical process by which most gray-iron engine parts can be cast. The coring of intricate interior surfaces or the formation of complicated exterior surfaces add complications to this casting process. Unless care is observed in design, the most economical production may not be obtained.

By careful study it is sometimes possible to reduce both the number and the weight of dry-sand cores required to produce engine castings. Separate core assemblies requiring pasting and nailing can sometimes be eliminated, as has been accomplished with the Pontiac V-8 engine cylinder heads and cylinder block. Core driers are expensive items, and their effect upon casting production should be considered by the product engineer. Cost reductions are sometimes possible by the substitution of green-sand cores for dry-sand cores and by designs which make possible the elimination of core wires for reinforcement. Other considerations in casting design would include: proper choice of wall thickness, elimination of fragile projections on cores, consideration for machinability of the castings, and the appearance of the castings.

The final responsibility for the economical production of castings naturally rests with the foundry itself. However, through a recognition of foundry problems and the factors which influence costs the product engineer can hope to design castings which are fundamentally easy to cast.

The Care and Handling of Liquids in Manufacturing Processes

By DAVID MILNE
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Three pronged attack reduces hazards of flammable liquids

In the manufacture of its products, General Motors makes use of a surprisingly large variety of liquid materials through an even greater variety of processes. The flammable nature of many of these liquids requires that a great deal of caution be exercised in their use, and also that a considerable sum of money be spent for fire and explosion preventive devices, fire fighting facilities, and building and process engineering for fire prevention. The ideal solution is, of course, to replace the flammable liquid with one which will not burn, or to replace the process with one which does not use flammable liquids. Industry sometimes must be satisfied with less than the ideal, however, at least until new knowledge of materials uncovers a satisfactory non-flammable substitute. With respect to flammable liquids, the hazard involved in the use of these materials can be lessened in three ways: (a) substitution of a less flammable liquid, (b) substitution of a non-flammable liquid, and (c) substitution of a process which will produce equal or better results but which uses no flammable liquids.

Two questions might be asked as an introduction to the use of liquids on the production line. First, what are the basic liquids used in manufacturing processes and second, what are these liquids used for? Technically speaking, there are only two fundamental classes of liquids available for use. The first class would be the inorganic liquids such as water and liquid ammonia and their solutions. The second class is that of the organic liquids which vary from the simple hydrocarbons to highly complex mixtures of natural products.

In the inorganic group is found one of the most commonly used liquids in manufacturing. This liquid is water, used either by itself, as a solute, or as a suspending medium for various other materials. Liquids which depend on chemical reaction with a surface to produce the intended effect are usually found in this group. Although liquid ammonia is included in the inorganic category, it is not used in manufacturing in the liquid state but is processed through various mechanisms which convert the liquified gas into other more convenient materials.

Under the heading of organic liquids, the classifications of flammable and non-flammable liquids can be established at least for the purpose of this paper. The organic liquids are those which contain carbon as an integral part of the molecule. These organic liquids exist in almost infinite variety, either alone or in combination with others. The range of organic liquids used in manufacturing processes can be appreciated somewhat by reference to the following list of the chemical names of the groups to which these liquids belong:

- Saturated hydrocarbons (most petroleum products)
- Unsaturated hydrocarbons
- Alcohols
- Esters
- Ethers
- Organic acids
- Aldehydes
- Ketones
- Aromatics (coal tar derivatives)
- Halogen derivatives of each of the above
- Nitrogen derivatives
- Sulphur derivatives.

With few exceptions, all organic liquids can be made to burn. The criterion of flammability, however, is whether or not the liquid will continue to support combustion by itself when the original source of flame is removed.

Between the areas of inorganic and organic liquids there exists another classification known as the emulsions which are created by mixing two immiscible liquids such as water and oil. An oil-in-water emulsion, for instance, is simply water through which oil droplets have been dispersed in varying concentrations. Conversely, a water-in-oil emulsion has the water droplets suspended in the oil medium. The oil-in-water type of emulsion is used extensively in manufacturing processes.

What are liquids used for? The following list indicates some of the fundamental uses of liquids in industry:

- As a means for conveying some other material which is left behind as a residue after the volatile fluid evaporates (paints, rust preventives)
- As a means for conveying heat to or from a process (cooling water, quench oils)
- As a medium for transmitting power (hydraulic fluids)
- As a means for removing soil or dirt from a surface (cleaners)
- As a chemical or electro-chemical reactant
- As a fuel
- As a lubricant
- As potable and boiler water supply
- As a means for conveying solid matter from one location to another.

In reviewing the uses for liquids, it becomes obvious immediately that in only one of the uses is the flammable nature of a liquid essential to its performance. It is only when a liquid is used as a fuel that it must be capable of

Fig. 1—The fire fighting apparatus shown above is typical of the equipment which must be maintained at all GM Divisions where flammable materials are used.

burning. In all of the other applications flammability is an unnecessary and objectionable feature of the liquid.

The objectionable feature of flammability is further emphasized when one considers the great amount of money that must be spent to protect personnel and buildings from fire and explosion. Many flammable liquids could be replaced with less hazardous ones, but the cost might be higher. This might be justified, however, as less money would have to be spent for the purchase, installation, and maintenance of fire protection equipment.

Factors Involved in the Handling of Flammable Liquids

To obtain some concept of the hidden costs involved in using flammable materials, a review of some of the factors which must be considered in every area of activity concerning these materials is helpful. In general, there are six areas of activity as follows:

(a) Unloading

(b) Storage

(c) Distribution

(d) Preparation for use

(e) Use

(f) Disposal of used materials.

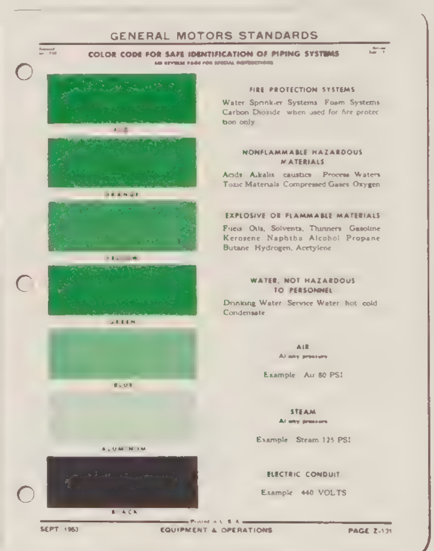


Fig. 2—General Motors Safety Standards specify a system of color coding for piping systems installed in any of its manufacturing plants. In addition to color, which establishes the class of material carried by the system, lettering is used to denote specific content. Lettering may be either black or white, whichever gives the greatest contrast with the background color, and may be applied by heat-resistant adhesive bands, stenciling, tagging, or any other legible and durable method. All piping carrying hazardous or flammable materials is further identified by arrows showing the direction of flow. Air, steam, and high-pressure water lines are identified by lettering as well as numbers which indicate pounds per square inch, abbreviated psi.

Unloading

When a flammable liquid is brought into a plant, certain practices and regulations must be observed during the unloading of that material whether it is received by tank car or truck or in smaller containers such as drums. Every step in the unloading procedure must be supervised and regulated carefully to prevent accidental ignition and fire. In the case of tank cars, each step in the unloading procedure is governed by well defined rules which have been set up by authorities familiar with the hazards involved. The safeguards prescribed for these unloading procedures necessarily make the operation more costly.

Storage

A flammable liquid unloaded from a tank car or tank truck may frequently be stored in the containers to which it is unloaded. These containers or tanks frequently serve as the central source of supply of that liquid for the entire plant, and provision is made for pumping this fluid to various parts of the plant.

The tanks used for storage of flammable liquids again are surrounded with protective devices and facilities, and strict regulations must be set up to control the activities of personnel approaching or working near these facilities. When flammable liquids are stored in drums, definite regulations must be placed into effect governing the construction of the storage area and its location. Whether tank storage or drum storage is employed, fire protection and fire fighting facilities must be installed (Fig. 1).

Distribution

The distribution of flammable liquids to processing areas may be accomplished by a wide variety of methods ranging from the issuance of small pail quantities to drums and, in the case of large flow, to pipe distribution systems operating under pressure. The well operated plant requires regulation of each of these methods of distribution to the point of insisting on special types of pails, special handling facilities for drums, and special regulations governing the installation of piping systems for the distribution of flammable liquids.

In each case, standard color codes are established to indicate the contents of

the containers or piping system. For example, the General Motors Standard Color Code for Piping requires that a pipe system carrying a flammable liquid be painted yellow and that it also carry lettering describing the contents of the pipe and arrows indicating the direction in which the liquid flows (Fig. 2).

Preparation for Use

Certain flammable liquids brought into a plant cannot be used as received but must be combined with other materials before use. This preparation is usually accomplished in a mixing room. Regulations for controlling the mixing room's location and construction are quite strict. For instance, with reference to location, General Motors insists that operations which are very hazardous be located in separate buildings, or at least located adjoining an outside wall and separated from other operations by a specially designed fire wall with protected openings. Such special hazards may not be located adjacent to or under cafeterias, toilet rooms, and other enclosed areas where employes might be trapped in case of fire. Recommendations for construction of these areas are specific and include provisions for the retention of spilled liquids, grounding of liquid containers, explosion relief vents, and exhaust ventilation.

Use of Flammable Liquids

Generally, flammable liquids are kept under cover (with the exception of the mixing rooms) until they arrive at the point of use where they are then usually exposed in open tanks or by spray mechanisms. Obviously, the hazard at this point is much greater and extreme measures must be taken to prevent accidents through ignition of the vapors. This is particularly true where these liquids are sprayed or atomized in use because vapor concentration is increased by the exposure of much greater surface area to the atmosphere.

Every piece of equipment as well as every utility supplied to that equipment together with the physical building facilities with which the equipment is surrounded must be examined in detail to determine whether or not some possibility of ignition of fluid vapors might exist. Appropriate measures must then be taken to eliminate any possibility of fire or explosion from these facilities (Fig. 3). In addition, complete and adequate fire detection and extinguishing equipment suitable for the material in use must be supplied.

Fig. 3—This interior view of a modern paint-spray booth illustrates the use of several safety measures both in construction and in supplying utilities to the booth. The booth is protected by sprinkler heads. Air, introduced at the top of the booth, flows down past the operators through the grids in the floor to remove solvent vapors and excess paint.

Disposal

The job of fire and hazard protection is not finished with ultimate use of the material. In many cases, flammable liquids are not completely used in the process and must be removed and either discarded or recovered depending on the usage the material has received. In the case of certain solvents, recovery may be accomplished by means of filtration or distillation procedures. In other cases, use of the material may have resulted in a type of contamination which cannot be removed to make the material fit for its original use or for some substitute use. Also, the volume of liquid involved may be too small to make recovery worthwhile. Under these circumstances the liquid must be discarded.

Whether the liquid is to be recovered or discarded, the operation involved must be controlled to prevent fire or explosion. For instance, it would not only be against the laws of most communities but would be decidedly dangerous to dispose a flammable liquid through a plant sewer. If the sewer discharges directly to a stream, not only would a dangerous condition exist in the stream but a great amount of pollution would be injected into the water course as well. If the sewer connects to a municipal system and eventually passes through a treatment plant, then even more hazard is involved.

At any point in the sewer system some outside source of ignition may cause a serious explosion of the gases and vapors present in the sewer. Careless disposal of flammable liquids in a municipal sewer has resulted in injury and death to passersby in the streets under which the sewers flow and also in very costly repairs for sewer installations wrecked by the explosion. When a flammable liquid arrives at the sewage treatment plant, sparks from operating equipment may cause an explosion which can injure personnel and destroy the operating mechanism of the plant.

An industry discharging flammable liquid wastes is, of course, legally responsible for any damage done to sewage treatment facilities and injury to personnel through ignition of these liquids. Obviously, careful regulations must govern any disposal activity involving flammable or hazardous liquids.

Safety Considerations in Areas Where Flammable Liquids Are Used

It should be obvious that the great degree of control exercised over the different areas of activity surrounding the use of flammable materials results in considerable expense to the using organization. Effective protective measures at each stage of handling of the material cannot be accomplished cheaply. Moreover, besides the initial installation of these facilities, a continuous program of maintenance, testing, and repair must be included. This represents a continuing expense which must be charged to the use of the flammable liquid.

It seems elementary to point out that there is nothing very dangerous about a so-called flammable liquid until some source of ignition is introduced. In almost every case the introduction of this source of ignition is the result of human failure to anticipate what will happen under certain circumstances or thoughtless use of spark or flame producing devices.

The person who installs a switch or piece of electrical equipment with open contacts in a location where hazardous flammable fluids are used is just as guilty of carelessness as the person who walks into the same area with a lighted cigarette. Unthinking or careless workmen can set off disastrous fires by the use of welding equipment for maintenance operations in unsafe areas without proper fire protection. At the same time, accumulation of static charges by improper grounding of equipment or personnel can produce the same results. For this reason, regulations even include such seemingly odd requirements as prohibition of the use of rubber footwear in certain hazardous areas.

Flammable liquid vapors, being heavier than air, may flow like an invisible river for considerable distances. Each location where these materials are used should be surveyed carefully with this in mind to make certain that no source of ignition is present within reasonable distances of the operation. Operators responsible for the handling of flammable liquids at any point in the plant should be thoroughly instructed in proper safeguards for their own protection and for the protection of the plant itself. In this respect, considering the hazard involved and the tremendous potential for destruction in the liquids being handled, familiarity must never be permitted to develop into contempt.

Fig. 4—Die casting machines such as this make use of petroleum-base hydraulic fluids in close proximity to molten metal. Careful design and use of non-flammable hydraulic fluids is necessary to insure freedom from fire in case of equipment breakdown.

Substitution of "Safe" Liquids

Two directions may be taken toward reducing the problems and cost involved in the use of flammable liquids for processing. The first is to substitute a liquid which is less flammable than the one previously used. For instance, in certain cleaning operations in which petroleum solvents are used, it may be possible to substitute a solvent with a considerably higher flash point.

While this obviously does not decrease the fire potential from the standpoint of contributing to or sustaining a fire, it does reduce the possibility of igniting vapors by some accidentally produced spark. This consideration applies, of course, only to those solutions which are used at a temperature sufficiently below the flash point temperature of the liquid. Certain cities, for instance, prohibit the use of organic flammable materials for any processes if their flash point is within 50°F of the operating temperature of the liquid.

As an interesting sidelight to the relationship between operating temperature and flash point, it has been found that fires can be extinguished quite easily in large quantities of relatively flammable materials, such as fuel oil, by simply lowering the temperature of the solution. This is usually accomplished by vigorous agitation of the liquid by means of air so that cool liquids from the bottom of the vessel are circulated to the surface. This lowers the temperature of the surface liquid, lessens the quantity of volatile vapors being discharged, and thereby lowers the vapor concentration in the air to below the lower flammability limit.

The second approach to the use of safe liquids for manufacturing processing is to substitute one of the so-called "non-flammable" liquids. According to Webster, the term "non-flammable" means "not flammable; capable of being burned when subjected to fire, but not supporting flame." While there is some insistence at present on describing these liquids as being "fire resistant" rather than "non-flammable," due to the fact that the liquids will burn when subjected to fire, it seems that Webster's definition covers the type of materials being described.

Development of these non-flammable liquids and their use in processing has been emphasized for equipment with which there is a definite fire hazard. This is the case with machinery which depends upon petroleum-base liquids as actuating media for hydraulic components, particularly where these hydraulic systems come in near contact with flame, spark emitting areas, or extremely high temperature surfaces in the equipment. Such situations exist with furnace door actuating mechanisms, electric welding equipment, or die casting equipment (Fig. 4).

Experience has shown that sources of ignition exist in almost every area of a plant and that these petroleum-base liquids may be ignited from an entirely unexpected source. For example, a baling machine (which is used to compress scrap metal into blocks) would not ordinarily be considered as a hazardous location. Recently, however, a leak in the hydraulic system actuating a baler caused a fine jet-spray of petroleum-base liquid to strike an unprotected electric light bulb in the pit in which the equipment was located. The bulb shattered, and the hot filament ignited the spray of oil. This, in turn, ignited the oil which had leaked out of the machine and had accumulated in the baler pit. The equipment damage, loss of operating time, and repairs to building facilities due to the resulting fire were extremely costly. The balers are now supplied with a non-flammable hydraulic liquid to prevent such an accident from happening again.

Physical Characteristics of Fire-Resistant Substitutes

Several basic physical characteristics must be studied in any liquid which is proposed as a more fire-resistant substitute for a flammable liquid in process. These characteristics are flash point, fire point, autogenous ignition point, explosive limit, and differential evaporation rate.

Flash Point

The flash point of a liquid may be defined as that temperature at which the vapors released by the liquid will ignite momentarily in air when a source of ignition is brought into contact with them. The temperature at which this flash is observed is not necessarily the temperature at which the liquid will take fire and continue to burn. It can be considered, however, as a rough measure of the comparative flammability of liquids. Obviously, the lower the flash point, the more flammable the liquid.

Fire Point

The fire point is defined as the temperature at which a liquid will take fire and continue to burn in air when a source of ignition is present.

Autogenous Ignition Point

The autogenous ignition point indicates the temperature at which the vapors of a liquid will ignite spontaneously without contact with an ignition source. A Diesel engine fuel, for instance, ignites because its ignition point temperature is exceeded during the compression stroke of the engine. Damaging explosions have occured in oil-lubricated air compressors apparently due to this "Diesel effect."

Explosive Limit

When the vapor of a flammable liquid is mixed with air in gradually increasing proportions, a point is reached which is known as the lower explosive limit. At this concentration the mixture of air and liquid vapor will ignite with explosive violence in the presence of an ignition source. As the concentration of vapor in air is increased, an upper explosive limit is reached. When the concentration of vapor exceeds this upper explosive limit, the mixture will no longer ignite in the presence of an ignition source and no explosion takes place. The concentrations of vapor and air existing between the upper and lower explosive limits is known as the explosive range of the liquid.

It should not be assumed that explosions take place only when the vapor concentration of a flammable liquid, when mixed with air, is within the explosive range. Explosions also can take place when relatively high flash-point materials are atomized in air in the presence of a source of ignition. The high temperature at the source of ignition vaporizes the droplets in contact with it to produce an air-vapor mixture within the explosive range. Rapid burning of this mixture raises the temperature of adjoining droplets so that they in turn vaporize and produce the same explosive mixture. Flame propagation through such an atmosphere accelerates with explosive force and the resulting detonation is every bit as severe as one produced by a vapor-air mixture.

Differential Evaporation Rate

The differential evaporation rate is a characteristic of mixed solvents having different evaporation rates. When a non-flammable solvent such as trichloroethylene is mixed with a flammable solvent the proportions chosen are usually such that the liquid will not burn. On exposure to air, however, the more volatile trichloroethylene may evaporate more quickly, leaving behind the highly flammable solvent. This creates a false sense of security in using this type of solvent. Continued use of the mixed solvent in an open tank will create an extremely dangerous condition which will be unknown to the operator unless the mixture in the tank is tested for flash point at frequent intervals. This may be rarely done in production operations, and the fire hazard existing in the operation is obvious.

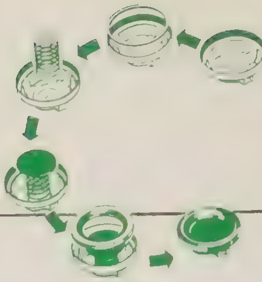
While the foregoing considerations for establishing the relative value of a fire resistant fluid cover the degree of flammability of the liquid, they are by no means the only criteria by which a liquid would be selected for use. Many other equally important factors must be considered. In some cases, for instance, good lubricating characteristics are required in the liquid. In nearly every case a liquid must be chosen which is not only fire resistant but non-toxic to operators. The effect of the liquid on equipment in which it is used must be evaluated to make sure that no extensive and expensive replacement of parts will be necessary.

Summary

Many types of flammable liquids are being used in connection with manufacturing processes—coolants, hydraulic fluids, solvents, thinners, and lubricants to mention a few. While such liquids are hazardous, rigid adherance to specifications for their use reduces the risk tremendously. Nevertheless, much attention is being given to the development of either non-flammable or less flammable substitutes.

The areas in which advances have been made as well as the specific requirements for the substitution of non-flammable liquids in manufacturing processes will be discussed in another paper to be published in a forthcoming issue of the General Motors Engineering Journal.

Trends and Principles in Progressive Mechanization



By HOWARD L. ROAT
AC Spark Plug Division

Ancient man's power was in his muscles. This manpower built the Egyptian pyramids, the Hanging Gardens of Babylon, and the Appian Way. But almost since written record man has sought to transfer his work load—first to animals, then to other men he called slaves, and, finally, to machines. During the past two decades, American industry has demonstrated its ability to produce at rapidly increasing rates. One of the answers for this increase has been the introduction and the development of automatic controls. Though the aim of delegating man's tedious and dangerous work to the machine is not new, the term "automation" as applied to automatic controls in a manufacturing concern is relatively recent. In this interview, Howard L. Roat, director of production engineering at AC Spark Plug Division, answers an editor's questions in an area which is of importance in every GM production location. Speaking from his experience and everyday contact with automatic machinery, Mr. Roat defines and discusses the field—its place in a manufacturing plant, and its possible effects upon industry and employes.

Automatic machines will aid men but never replace them

IN THE preparation of his answers to the GENERAL MOTORS ENGINEERING JOURNAL questions, *Howard L. Roat* draws on more than thirty years of industrial experience with General Motors. In July 1925 he joined Chevrolet Motor Division, Flint, Michigan, as a designer. From 1927 until 1933 he served Buick Motor Division, also in Flint, as a die designer. Since July 1933, when he transferred to AC Spark Plug Division as a draftsman, some of the capacities in which Mr. Roat has served this Division include die designer, designer, inspection foreman, inspection superintendent, vocational education—special assignment, supervisor of employe relations, general supervisor of drafting, assistant supervisor of the Tool Room, and chief process engineer. In 1951 he was promoted to his present position as director of production engineering.

In his capacity as director of production engineering Mr. Roat is in charge of the planning and execution of AC Spark Plug's tool engineering programs for both commercial and defense products. Associated with these duties is the supervision of the methods engineering and the suggestion investigation activities, coupled with the management of the manufacturing development for new processes—including the tool rooms which maintain production tools and equipment and which build a portion of the new facilities required for the Division's products.

Mr. Roat is a 1929 industrial engineering graduate of General Motors Institute, Flint, Michigan. Since his graduation he has taken supplemental G.M.I. courses in hydraulics, pressed metal operations, and management.

Mr. Roat has completed numerous speaking engagements before various technical society meetings and before engineering groups. In general, his topics have been in the fields of progressive mechanization and industrial engineering.

Mr. Roat is a member of the American Society of Tool Engineers and the Society of Automotive Engineers. In addition, he is a registered professional mechanical engineer of the State of Michigan.

Q: Mr. Roat, we hear so much today about the trend toward improving the man-machine relationship in manufacturing operations. Would you comment on this trend which some technical folks have called "automation?"

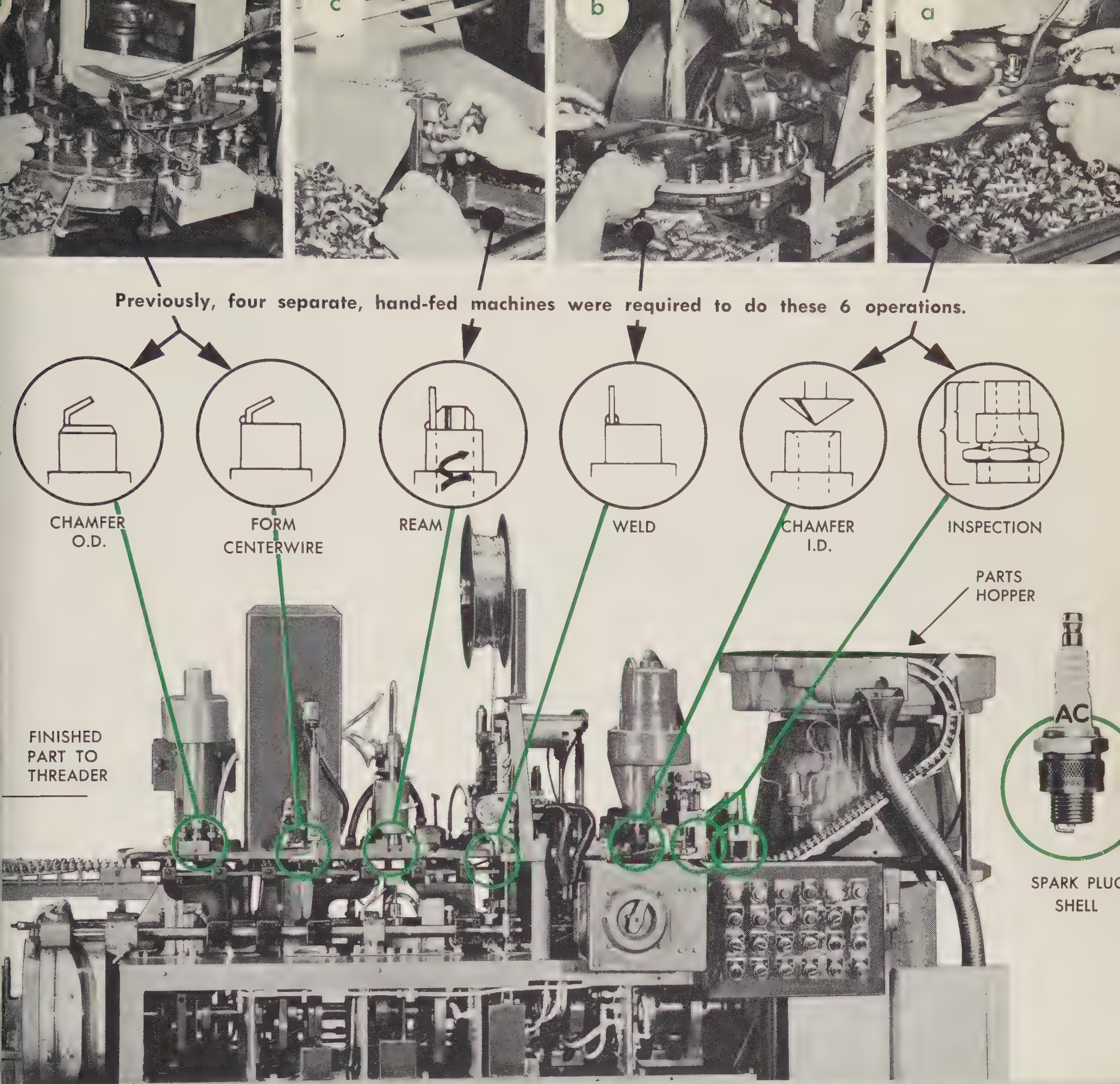
A: I would interpret this trend of progressive mechanization as one toward the mechanical handling of a part or assembly of parts in such a manner that human effort is not required to transfer parts to perform a sequence of operations. It sometimes includes both the automatic unloading of one machine and the automatic loading of the next.

Automatic devices include mechanisms that are designed to push, pull, rotate, grasp, and lift parts and those that load parts for machining, assembling, welding, brazing, and inspecting operations. These devices are timed to coordinate their movements with the speed of the process and ordinarily are completely automatic while in operation or require only a minimum of manual handling.

Q: Is this trend really new? What very early examples of automatic production can you recall from your own experience?

A: Actually, automatic control, in some form, has been a reality since the steam age. Perhaps the start of completely automatic production was in 1784 with the development of the first assembly line built by Oliver Evans in his factory for processing flour—the first entirely automatic factory.

Some of AC Spark Plug's early accomplishments in this field included a rotary-type machine for welding the side wire to spark plug

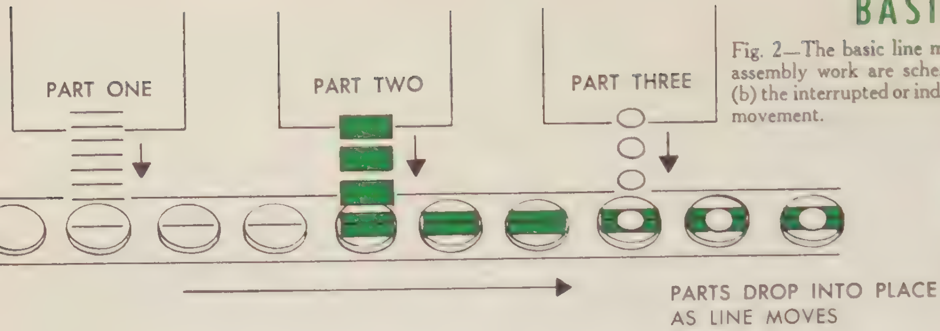


SPARK PLUG STRAIGHT LINE SHELL AND WIRE MACHINE

Fig. 1—Designed and developed by AC Spark Plug engineers, the special machine illustrated above has served to fulfill the objectives of progressive mechanization by eliminating many monotonous, repetitive operations previously performed by hand. These operations were: (a) burr inside diameter, (b) weld side electrode, (c) ream inside diameter, (d) form centerwire, and (e) chamfer outside diameter. Spark plug shells, received from primary operations, are fed into the machine from the hopper shown at the extreme right. At the first and second stations in the machine inspection operations are performed to verify dimensions. The third operation involves removal of the cut-off burr by chamfering the inside end of the shell. Next, the side wire is welded in place and the wire cut to the proper length. At the fifth station a reaming operation is performed to remove the weld flash from the inside edge of the shell. Following this the side wire is formed to the proper shape. At the last station the outside cut-off burr and weld flash are removed by chamfering the end of the shell. A transfer mechanism transports the shells through the various inspection and work stations. At each station cam-operated guide posts raise each piece to the desired work height for either an inspection, machining, or welding operation. The welding unit performs more than the welding operation alone. The unit feeds the side wire into place from a continuous coil, cuts it to the proper length, and then butt-welds it to the shell.

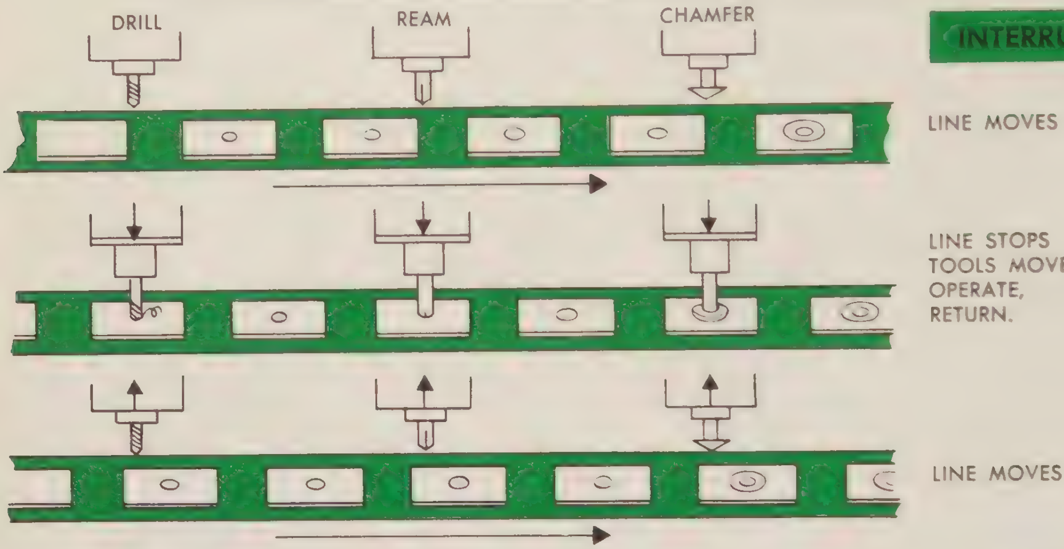
BASIC LINE MOVEMENTS

Fig. 2—The basic line movements used in inline machines for either machinin[g] assembly work are schematically described here as: (a) the continuous conve[yor] (b) the interrupted or indexing conveyor, and (c) the transfer, or advance and ret[urn] movement.



CONTINUOUS MOVEMENT

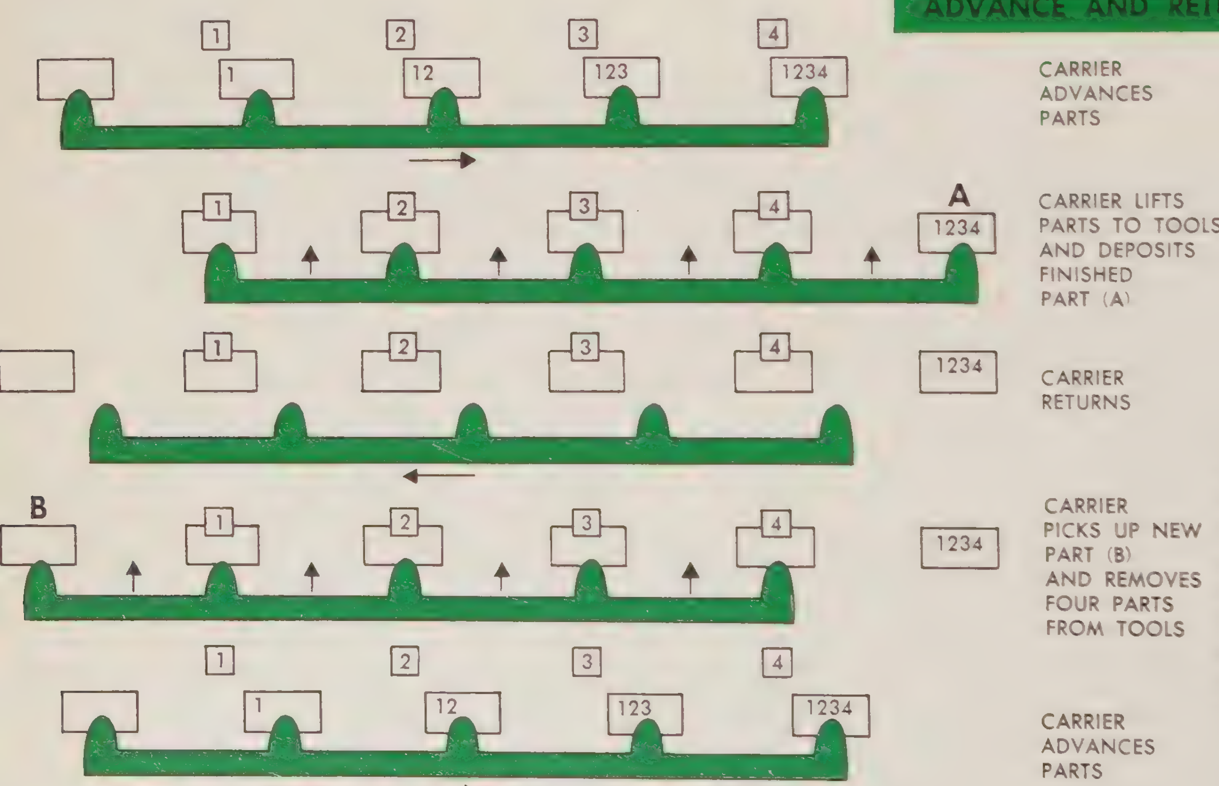
(a)—The continuous conveyor is the simplest of [the] three basic line movements—generally its cost [is] lower and cycle speed higher than the intermitt[ent] types.



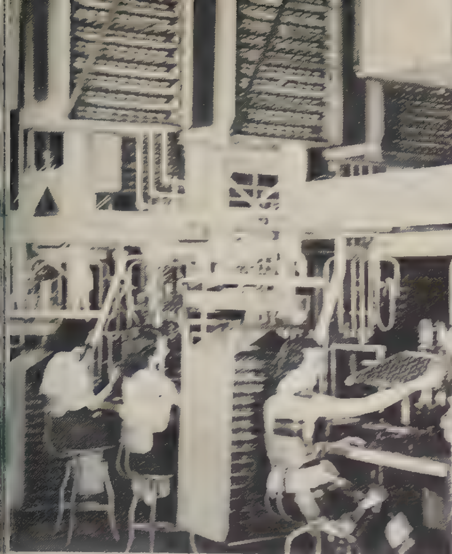
INTERRUPTED MOVEMENT

(b)—The interrupted or [in]dexing conveyor is the m[ost] conventional type of mov[e]ment used where a time [in]terval is required at speci[fic] stations to perform an opera[]tion. This type is usually [ex]pensive due to the number [of] stations requiring a comple[te] set of fixtures.

ADVANCE AND RETURN MOVEM[ENT]



(c)—The transfer, or [ad]vance and return, move[ment] is used in many punch [press] applications where the [part] is moved through the [se]quence of operations [by] means of transfer bars [and] fingers which grasp the [part] during the transfer o[pera]tion. This type is [more] economical than the i[nter]rupted or indexing typ[e of] movement.



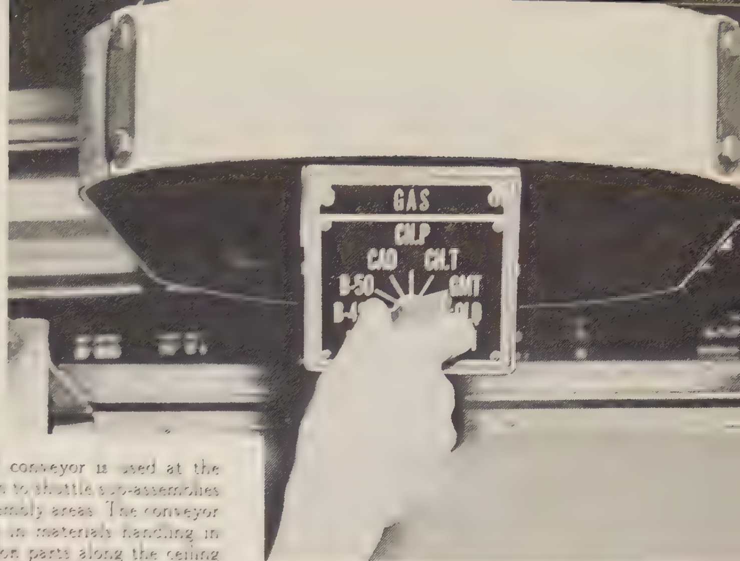


Fig. 3—This overhead conveyor is used at the AC Spark Plug Division to shuttle sub-assemblies from production to assembly areas. The conveyor reflects a new concept in materials handling in that it moves production parts along the ceiling rather than across the floor. This technique of conveyor installation has reduced production and storage costs, made better use of existing floor space, and minimized safety hazards. Each parts carrier on the conveyor is controlled by a scatter selector switch, the setting of which determines the carrier's destination. In the sub-assembly area of AC's Instrument Department such parts as speedometers, oil gages, gasoline gages, ammeters, mechanical and electrical thermogages, and transmission indicators are assembled and placed on carriers. By setting a selector switch each carrier can be dispatched to any one of 47 final assembly stations where it is lowered from the conveyor-rail to bench level. The system operates on the *power and free* principle. Power is supplied to the carrier only when it is on the main line of the conveyor; eleven free side tracks are available to hold the carrier above a work station until it is needed.

shells, a special machine for printing the odometer wheels for speedometers, and a transfer press for speedometer cases. The latter included an adaptation of the first electric eye for stopping the press when a mistransfer was made. It was with the advent of World War II that concentrated effort was focused on the development of automatic controls. The wartime advances in the fields of electronics and electrical network analysis made possible the construction of a collection of self-correcting and self-programming machines which probably was the origin of the present emphasis on improving the man-machine relationship.

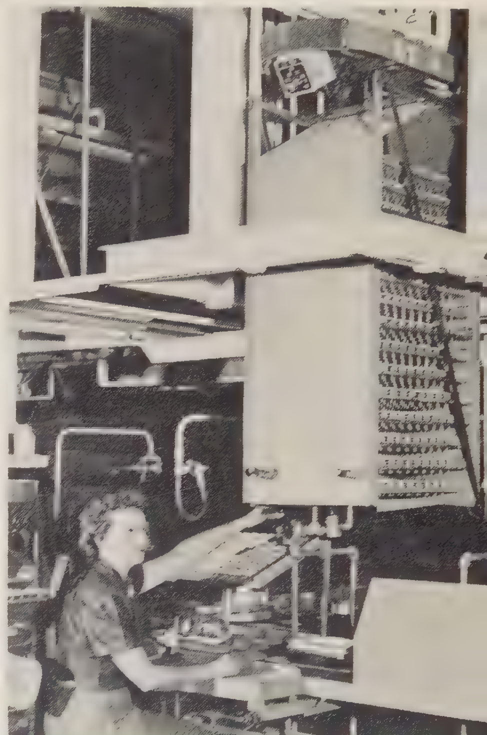
Some industries, by the very nature of their raw materials and their finished products, require automatic control. For example, work with radioactive substances must, of necessity, be done with a minimum amount of actual worker handling of the dangerous elements.

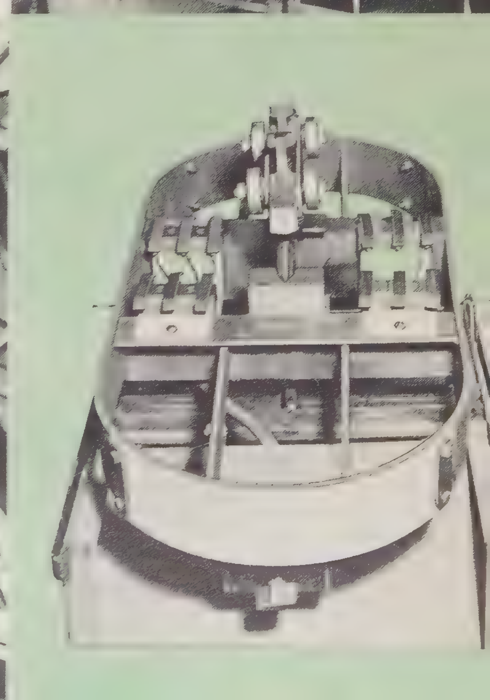
Q: Mr. Roat, what are the principles of progressive mechanization?

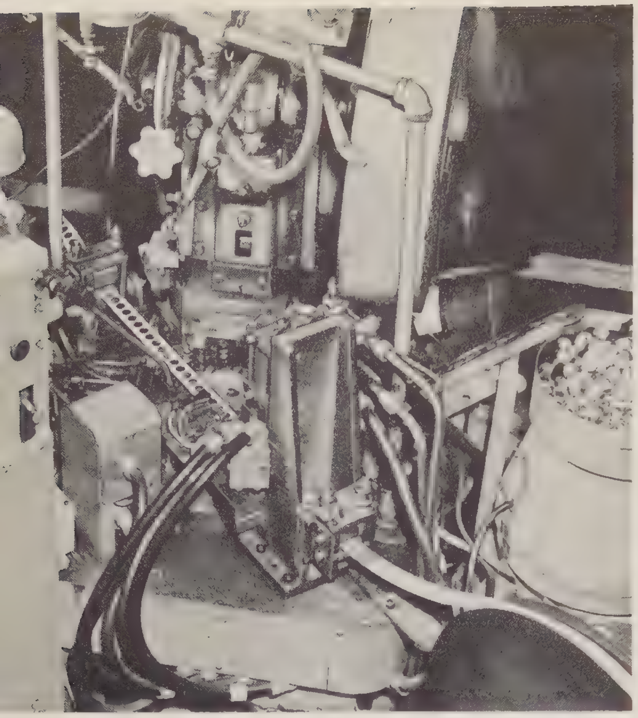
A: The principles of progressive mechanization when considered by management lie in two broad areas. They are the economic justification area and the material or physical construction area of the application.

The economic justification of an application of progressive mechanization concerns both the capital investment and the human element—namely, labor required, working conditions, human errors, physical fatigue, and the general raising of the standard of living of the worker, all of which must be considered when improving the competitive position of our company's products.

The principles which concern the material or the physical construction of the application are completely technical and utilize all the sciences. The broader knowledge the engineer and designer has in mechanics, metallurgy, electricity, hydraulics, and







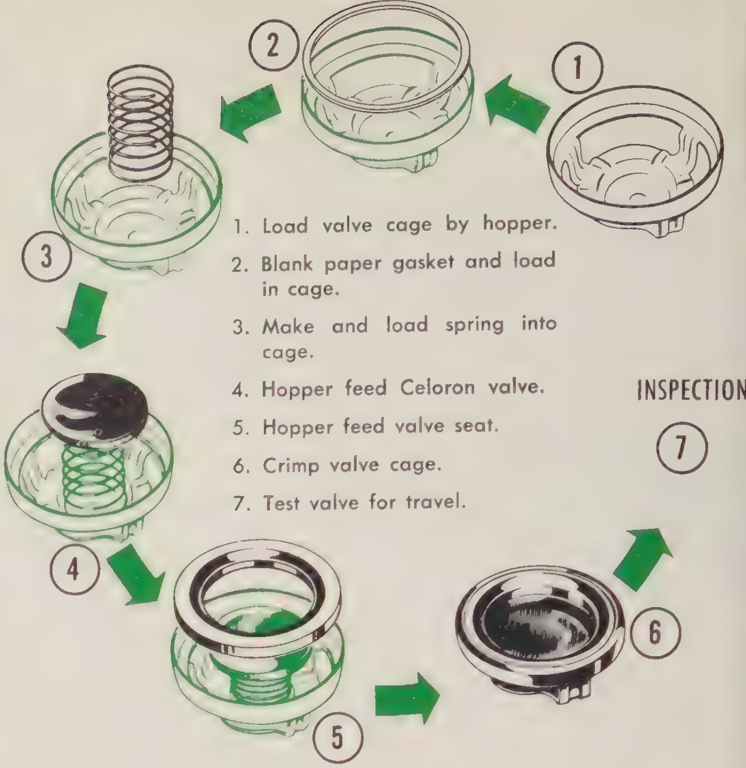


Fig. 4—Progressive mechanization was applied to AC's assembly line for fuel pump valve cages in the form of a rotary-type machine which performs several assembly operations, some of which are illustrated by the sketches shown above. The rotary-type machine is operated by a *set-up and operate* man. As the operators, previously used to perform the above sequence of operations, are made available by the installation of these machines, they are placed upon other operations within the manufacturing division. This transition is done on a gradual basis without actual displacement of any employe, but rather with a trend for higher-graded employes for operation of the automatic assembly machine. This machine was conceived and designed by engineers of the Manufacturing Development activity of the AC Spark Plug Division.

pneumatics, the more potential opportunities he will be able to conceive and solve in this era of integrated progressive mechanization.

Q: Mr. Roat, what is the main factor management considers in deciding whether or not to mechanize a process?

A: I would say that the main objective that a manufacturing concern hopes to achieve by converting to automatic equipment is the cost reduction of the finished product for the customer. This cost reduction in the product can be brought about through automatic equipment by: (a) increased productivity per operator, (b) elimination of human drudgery, and (c) improved product quality.

If mechanizing a process will mean an excessive expenditure of funds with no foreseeable return, special machinery would then raise the product's selling price—and most probably lower its sales. In this case, conversion to automatic equipment is both undesirable and unwise.

Q: Would you comment, please, on increased productivity per operator?

A: Using automatic equipment it is possible to increase productivity per operator from high-cost machinery. For example, on some press lines it is impossible to load the presses manually fast enough to keep them running continuously. The addition of automatic loading and unloading machinery allows the press line to operate closer to its designed capacity which is, of course, a definite cost saving advantage.

Q: Now, what of the second of the three motives?

A: Elimination of human drudgery is the second motive. One application of automatic operation utilized to reduce the physical labor and the time spent in moving stock and unfinished parts from one location in the plant to another is the overhead conveyor system installed at AC Spark Plug's Flint, Michigan, plant. Anyone along the assembly line can dispatch a carrier loaded with supplies and parts to any one of 47 final assembly stations, simply by setting a selector switch.

In addition, mechanization eliminates monotonous, repetitive work, such as loading and unloading a machine. Incidentally, by relieving the repetition, automatic controls often serve as a safety factor; the worker is less likely to let his attention wander and be injured if his job is challenging and interesting.

Q: You mentioned increased quality as a third factor.

A: Yes, in most cases mechanization results in a better product because it avoids the errors of human judgment caused by repetitive, monotonous reading of gages. One of the most striking examples of this at AC Spark Plug is a semi-automatic radiator-cap assembly machine designed and built by the General Motors Process Development Section. Three out of five parts are fed automatically into the machine and are assembled on an indexing carrier. Following assembly, the machine provides functional inspection for the spring rate and sealing quality of the cap. In addition, it is adaptable to five different cap models.

Q: Mr. Roat, you call these the main factors. Could you list some secondary factors that might be reasons for converting to automatic operation?

A: There are several conditions—in addition to cost reduction, increased

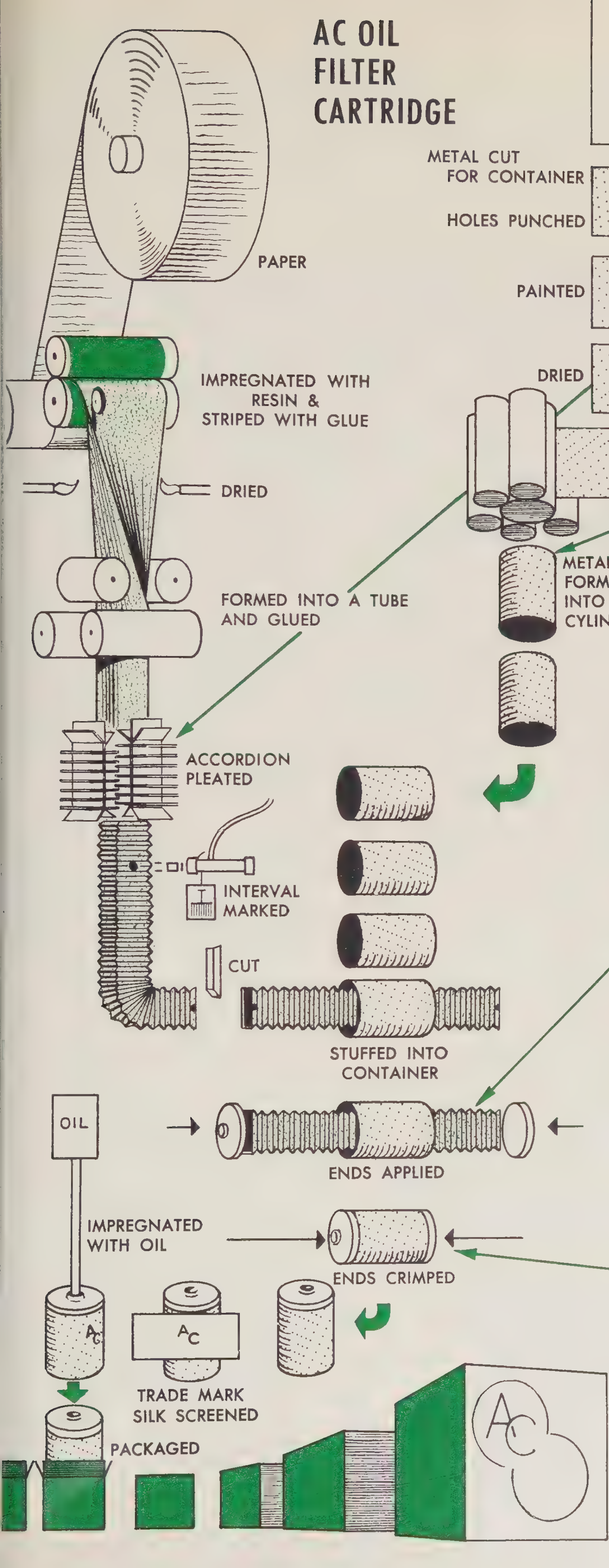


Fig. 5—The manufacture of oil filter elements has presented many opportunities for the application of progressive mechanization principles to both materials handling and special automatic machines for processing the various operations. Since oil filters are made in several sizes, more than one assembly line is used. Thus, AC engineers are continually at work to devise new and better handling and assembling equipment to perform the sequence of operations shown in this schematic diagram.

productivity, reduction of physical labor, and improved quality—to look for when considering automatic equipment, such as:

- Several operators performing the same operation
- Difficult and continuous handling operations
- Production "bottlenecks"
- High number of rejections due to the human factor
- Involved inventories due to large number of in-process parts on hand.

However, the presence of one or all of these situations does not necessarily mean that automatic controls should be introduced. Only by making a cost evaluation considering potential savings versus potential costs of the automatic equipment can the answer for management be found. Life expectancy of the product to be automated, the time required to build the equipment, and the time required to amortize the new facility are important considerations. When all conditions are considered, cost reduction of the finished product is the deciding factor.

Q: Mr. Roat, you described the radiator-cap assembly machine used in General Motors. Can you give us some other examples of automatic machinery?

A: The present automatic machinery falls into several general types. Some of the most prominent include:

- Straight-line-type machines in which the unfinished part is introduced at one end and emerges from the other end as a partially or completely finished part. A good example is the spark-plug-shell and side-wire machine.
- Rotary-type machine with a circular rotating table on which the finished unit usually returns to the position from which it was introduced as an unfinished part. An example is our spark-plug-insulator-glazing and printing machine.
- Transfer-type machine which passes a part from one individual operation to the next. The machine is loaded at one end and unloaded at the other with all in-between actions completely automatic. Our fuel-pump-body-machining unit is an example.

Some other general types are automatic screw machines; plating machines for zinc, cadmium, copper, nickel, and chromium; threading, knurling, and metal forming machines; die-casting machines; polishing and buffing machines; washing and chemical cleansing machines for metal parts; painting and drying machines; special welding, swaging, and heading machines; and continuous paper processing and forming facilities.

Q: Can you give us a broad, loose outline of just how a company would go about converting to automatic controls?

A: Our experience has taught us that first we must make a complete evaluation of the processes or operations to be converted to automatic controls and determine the economic justification of the application. At AC Spark Plug we employ methods engineers to determine the economic justification of the application of automatic controls. Then we assign development engineers to the designing and the perfecting of the apparatus; they study the product itself. Will it need to be redesigned? Will the redesigning improve it or will it only raise the cost without increasing the quality?

The engineers concerned make preliminary manpower estimates. Will the operator have to be re-trained extensively to operate and maintain the new equipment? Will more men be needed for assembly, observation, or manual control operations?

A general plant layout is made up showing all of the space and specific locations required. Then the plant layout, tool design, die design, and material handling engineering departments and the machine tool builders cooperate on a specific layout plan. Often, three-dimensional models and perspective drawings are constructed and studied. Can the standard machinery, already in use, be utilized with the addition of mechanical devices to eliminate manual handling or will special machinery have to be designed, purchased, or constructed in the plant? If standard machinery is used will it have to be moved or overhauled?

After all these questions are answered, the potential cost and profit of operating with automatic controls is evaluated in light of the present margin of profit. Sometimes, at this point, management finds it is financially wiser not to mechanize.

Q: Mr. Roat, in your opinion what effect will automatic controls have on production personnel?

A: As I have stated earlier, this idea of putting more and more of the burden on the machine is not a new objective. In the future, this growing emphasis on the use of automatic controls will increase the need for some production workers to be more highly trained than at present because of the specialized knowledge required to operate some of the machines. This will mean a more complete plant training program for part of the work force. In return, the worker will find his job more interesting and involving less physical labor. The worker has always been an important person and automatic operation merely makes him more important by removing tedious and bothersome work.

In addition to requiring better trained production personnel to operate mechanized equipment, industry will soon find that their needs for engineers, designers and all branches of the skilled trades will increase. A gradual transition from the unskilled production worker to the skilled trades worker will take place to meet the demands for this class of worker. This will raise the status of industrial personnel in general.

Q: Wouldn't the introduction of automatic controls into a manufacturing plant necessitate the redesign of the product in many cases?

A: Actually, the necessary redesigning of a product for ease of manufacture is not confined to the area of automatic operations. This situation is not infrequent today, even in the non-automatic or semi-automatic factory, and most manufacturing concerns set up special product and production engineering departments or sections to concentrate on this problem. Prior to switching to automatic operations, the product engineers and the production engineers join forces to smooth out any discrepancies that

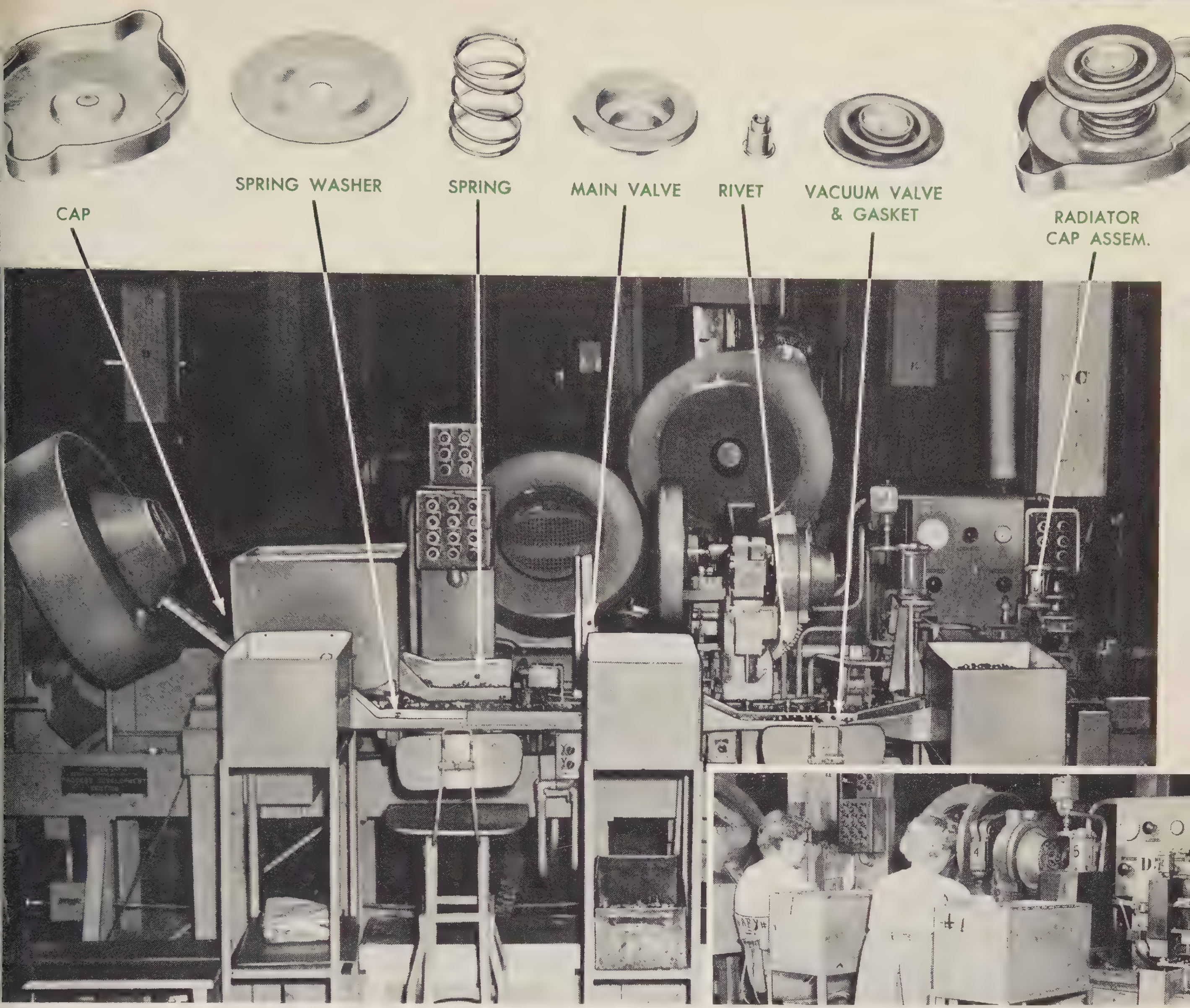


Fig. 6—The machine used at AC to assemble radiator caps is a good example of what can be done by combining operations and placing them in sequence on a straight line machine. There are seven work stations which perform operations as follows: (1) hopper-feed cap, (2) hand-load spring and spring washer, (3) hopper-feed main valve, (4) hopper-feed and stake rivet, (5) hand-load gasket and vacuum valve, (6) press vacuum valve into main valve, and (7) run functional test. A continuous chain moves 58 carriers, which are also the work fixtures, along the top of the machine and returns them through a channel near the floor. A retractable pin in each carrier serves to locate the parts as they are loaded and to curl the rivet which holds the radiator cap assembly together. The final work station of the machine tests the completed assembly for the correct spring rate and for leaks. Faulty assemblies are ejected automatically. Two operators are necessary to operate the machine and to load the four parts of the assembly, as indicated in the view above.

might occur between the drawing board and the assembly line.

Q: Suppose you were going to train to become an engineer in an age of mechanization, Mr. Roat. In the light of your experience with automatic controls what particular fields of knowledge would you investigate?

A: I would say an engineer needs a thorough foundation in mechanical engineering coupled with enough understanding of electrical and hydraulic engineering to be able to appreciate the appropriate application of each of these particular fields.

I visualize that the engineering executive of the future will be an engineering "generalist." That is, he will be a specialist in administration but, in addition, have enough working familiarity with the different fields of engineering—electrical, electronics, sonics, electromechanical, atomic energy, and hydraulics—to be able to understand and to work with engineering specialists in these areas.

Q: You mention the electrical and hydraulic engineer. How are they important to the field of automatic controls?

A: Quite often a finished piece of automatic machinery is made of standard parts, such as conveyors and air, hydraulic, and/or electrical controls set up to obtain the proper sequence of operations. And often, the engineer will design and supervise the building of his own machinery within the plant itself and with no outside parts or help.

Q: From your acquaintance with automatic operations and automatic controls, Mr. Roat, can you visualize an era in which industry will be 100 per cent automatic?

A: There is no denying that the majority of all industry is at least semi-automatic. On the other hand, there are very few, if any, factories without human participation, and I do not think that there will be for some years to come. Let me explain. In order to have a 100 per cent automatic plant, first the design of the manufactured product would have to be frozen to provide necessary time for each individual process in a plant to be mechanized. Then these processes must be integrated into a single, coordinated system. Finally, a single, master control must be designed.

Perhaps it is possible to build a control device with every possible problem anticipated. But would such a machine—expensive to design, costly to build and maintain—be practical? At the present time, the cost would be very high in comparison with the current cost of manual labor. But no matter to what degree the actual manufacturing operations in a plant may be mechanized, there will still be a need for trained technicians, designers, research scientists, and highly trained maintenance and production personnel. Automatic controls will aid men—they will never replace them.

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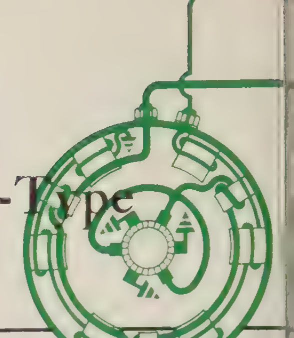
The Development of a High-Output Carbon Pile-Type Generator-Regulator



Regulation of the automotive electrical system presents a number of challenging problems. Variation in generator speed, performance, and load are tremendous when compared to conventional equipment. While regulation is usually accomplished by means of vibrating contacts, the design of a modern high-output generator, suitable for transit-coach application, called for considerably higher field current than existing vibrating contacts could handle. Thus, Delco-Remy undertook the development of a high-capacity carbon pile regulator. A marked improvement in generator efficiency and reduction in size resulted. Long life and freedom from maintenance make this regulator ideal for buses and other heavy duty applications.

On automobiles and other small vehicles, current and voltage control in the generating circuit of the electrical system is usually accomplished by means of a vibrator-type regulator. A typical regulator of this type consists of a cutout to prevent the flow of current from the storage battery to the generator when the engine is not running, a current limiter to protect the generator from overheating, and a voltage regulator to limit the system voltage to a value suitable for battery charging as well as optimum operation of the ignition, lights, and accessories. Regulation is usually accomplished by means of vibrating contacts in series with the generator shunt field, and the 2 ampere maximum which such contacts will handle is satisfactory for automobiles.

On larger vehicles, however, the power requirements are sufficiently high that 2-amp generator fields are no longer adequate. Even though the vibrator-type regulator is extremely simple and low in cost, its continued use on large vehicles, such as trucks and transit coaches, imposes severe penalties and limitations on the generator such as inefficient field coils or multiple fields with a regulator in each branch.

The tremendous demand for electrical

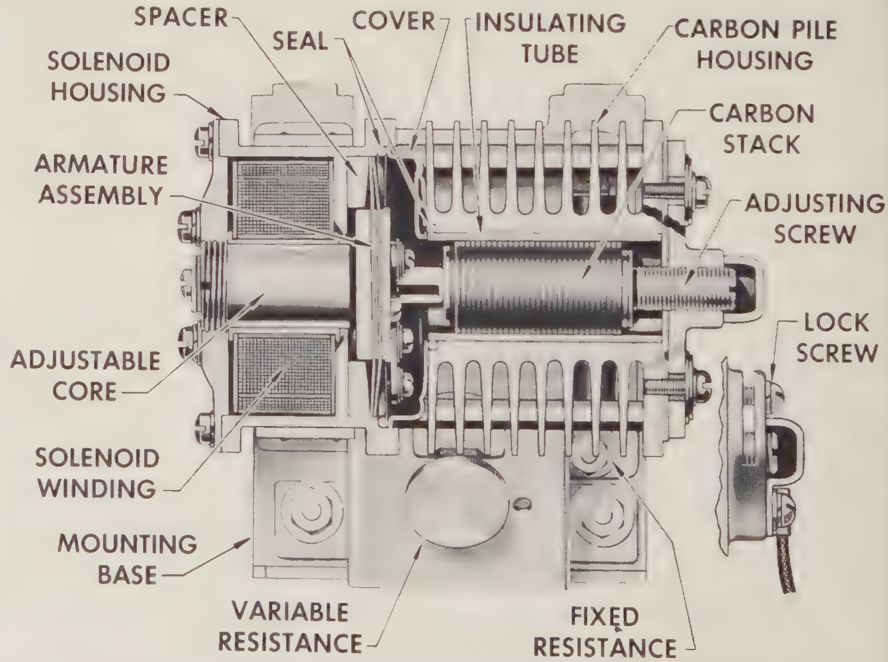


Fig. 1—This carbon pile-type regulator was developed by Delco-Remy engineers for use on military aircraft. Note the in-line construction which minimized weight but at the expense of accessibility and adjustment facility.

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Design successful in military aircraft is adapted to buses and other heavy-duty vehicles

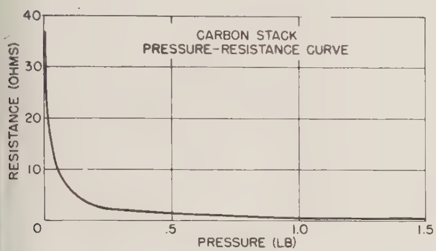

Fig. 2—The variation of resistance with pressure is shown for a typical carbon stack consisting of 40 discs, ¾-in. in diameter and 0.040 in. thick. Faces are lapped flat within 0.0001 in.

power in World War II aircraft made the regulator problem even more acute. In England, however, use was made, to a limited extent, of a carbon pile-type regulator which was relatively simple and direct-acting and which was capable of controlling generator field currents in excess of 2-amp. While power ratings were not adequate for the new requirement, good life could be expected under favorable operating conditions. In co-operation with the U. S. Air Force, Delco-Remy Division undertook the development of a more accurate, wider range, and higher capacity carbon pile voltage regulator for use in the 24 v electrical systems of military aircraft and made the first to be accepted for use on U. S. military planes (Fig. 1). Eventually this type of regulator was specified for use on all combat aircraft.

As the demand for electrical power on transit coaches increased, generator designs had to be considerably distorted in order to continue the use of the vibrator-type regulator. Contact life was still not entirely satisfactory, so this appeared to be an ideal place for the application of a high-capacity carbon pile regulator. Delco-Remy's experience in the aircraft field indicated that this type regulator

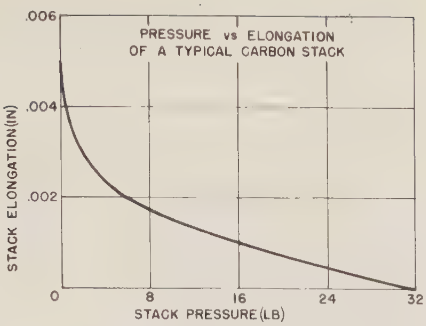

Fig. 3—The variation of length or elongation with reduction of pressure in a typical carbon stack is a measure of disc flatness and not the modulus of the material.

could help overcome the problems of excess weight, high inertia, and short service life. Since the carbon pile regulator could handle a greater amount of field current, a more efficient balance between field coil and armature windings could be effected, thus greatly improving overall generator design. With a stronger field, armature diameter could be reduced thus minimizing weight and rotational inertia. If stable operation and freedom from arcing in the carbon stacks could be assured, long stack life could be expected in contrast to the short service life of vibrating contacts as a result of continual arcing.

The carbon pile regulator, as designed for motor coach use, does have several fundamental differences from the aircraft regulator. In the military application performance requirements must be obtained within certain size and weight limitations. These size and weight restrictions are much less rigid in designing the regulator for motor coach use, and the primary engineering objectives become long life and serviceability of the unit. The performance criteria were as follows:

- Reduce weight of generator-regulator combination to a minimum
- Reduce generator rotational inertia to a minimum
- Increase maximum output by 25 per cent
- Increase length of trouble-free operation by 100 per cent
- Improve ease of maintenance.

Preliminary engineering studies indicated the first three objectives could be readily obtained by using optimum field excitation in the generator. The regulator's function was to vary the generator field current so as to provide the proper voltage and current over the speed and load range of operation. The generator design fixed the following regulator requirements:

(a) *Field current maximum and minimum*

These values are used to determine the maximum and minimum

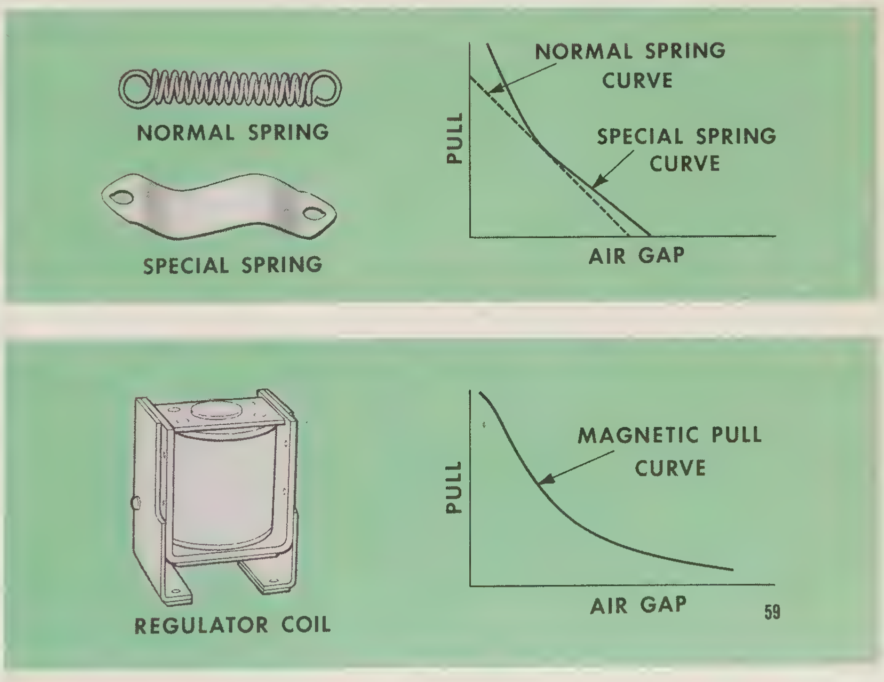

Fig. 4—Pull curves of a conventional helical spring, the special carbon pile spring, and the magnet show the change of force with change in air gap.

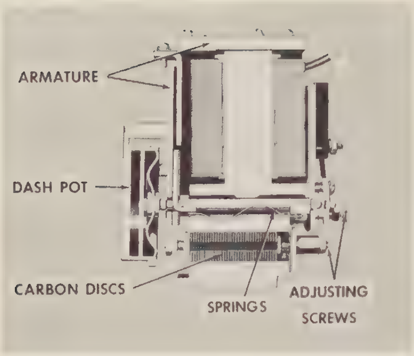

Fig. 5—This cross section of the fundamental regulating unit shows the double-loop type multiple spring developed by Delco-Remy engineers.

resistance to be inserted in the shunt field.

(b) *Maximum heat to be dissipated in the stack*

This is $(E/2)^2/Rf$, where E is system voltage and Rf is the resistance of the generator field.

(c) *Regulating stability*

Analysis of this quality is usually obtained by test rather than by calculation. Generally speaking, a generator with a good commutator and a definite increase in shunt field requirement with an increase in load or a decrease in speed is the most stable. The regulator must maintain a definite relationship between the solenoid pull curve and the calibrating spring curve over the entire range of operation in order to be stable.

The only requirement confined exclusively to the regulator is to maintain constant voltage setting over the operating range of speed, load, and temperature. Even this requirement is closely related to the generator design, since the range of generator control required has a direct bearing on the amount of work the regulator must do.

Preliminary Analysis

Following the usual practice in regulator design, as many existing parts as possible were used. The cutout required only a slight modification of production relays. The same type of unit was to be used for both voltage and current regulation. A suitable container to mount and protect the units could be more easily fashioned after the units were designed. Thus, the first step was to design a voltage regulator unit. This step was divided into four basic parts:

(a) The magnet
(b) The carbon pile or stack
(c) The spring bias to oppose the magnet
(d) The combination of these three basic parts for the most efficient operation.

Design of the Magnet

Since the forces involved were fairly high, the magnet had to be compact and rugged. A simple U-shaped frame with a cylindrical core was chosen because it satisfied these requirements and was easy to manufacture. It also afforded good surfaces for attaching other parts. The winding space was made essentially cubical.

Design of the Carbon Stack

The carbon stack required little change from the one used in military regulators. A grade of material best suited for this application was selected, and elongation and resistance specifications were established (Figs. 2 and 3).

Design of the Spring Bias

The spring bias required major redesign in order to obtain a spring curve which essentially paralleled the magnet pull curve. The match between springs and solenoid could have been accomplished by making a magnet with a straight line pull by iron saturation, but this would have required a much larger and a more expensive magnet. On the early regulators a multiple cantilever spring assembly consisting of 24 separate springs bore against a conical seat to produce a varying effective length and rate as the seating progressed. The reason for the critical setting is apparent since spring and magnet curves match for only a few thousandths of an inch travel.

The original conception of a tension spring which would give the required variation in rate (most springs follow Hooke's law where force developed is proportional to displacement) was a single piece of wire in semicircular shape, similar to the handle on a paint bucket. If tension is applied at the ends of such a part, it can readily be seen that elongation practically ceases as the wire becomes straight. In other words, the spring rate increases as curvature of the spring decreases. To verify the principle and to obtain a practical starting point a sample was made using a piece of 0.040-in. diameter music wire formed to a 3-in. radius for 180°. A pull curve was obtained by hanging different weights from one end and measuring deflection. The exponential rise of force with displacement proved that this type spring could be used to match the solenoid pull curve.

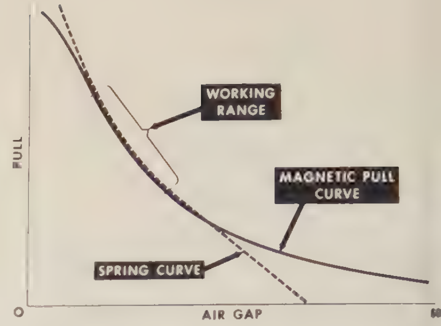

Fig. 6—The magnetic pull at a given voltage and the spring pull are practically identical over the working range, leaving all the force due to change in voltage available to apply force on the carbon stack.

At this point enough data had been collected to approach the specific problem of adapting the fundamental spring concept to the regulator at hand. From a casual analysis it was apparent that the spring was worked and stressed in a manner very similar to a simple beam. A rectangular cross section would make the most efficient use of material in such a spring, and any number of springs could be connected in series or parallel to give the required performance.

A survey of spring manufacturers and available literature failed to produce a stress formula for a spring of this type, so an approximation was developed based on the cantilever formula.

$$S = \left[\frac{6P_H l_{vo}}{bh^2} \div \left(1+\frac{4P_H L^2 \cos\theta}{Ebh^3}\right)\right] + S_t$$

where

S = stress in outer fiber—lb per sq in.
P_H = load—lb
l_{vo} = vertical offset (free position)—in.
h = thickness of spring—in.
L = a length (in.) determined by $\sqrt{l^2_{vo}+\left(\frac{l_H}{2}\right)^2}$ (approximately)
b = width of spring—in.
l_H = span of loop—in.
E = modulus of elasticity—lb per sq in.
θ = $\mathrm{Tan}^{-1}\frac{l_v}{\frac{1}{2}l_H}$
S_t = tensile stress due to load—lb per sq in.

This formula reveals a number of hings about the spring. Stress is proportional to load and to the amount of ffset. It is inversely proportional to the vidth and thickness squared. The factor $+ 4\, P_H L^2 \cos\, \theta / Ebh^3$ takes into account he reduction in stress due to decreased ffset as the spring is stretched.

From preliminary calculations and xperimental samples it was found that single spring which matched the solenoid pull was too large to fit well with the other components. Since the same curve ould be obtained from a multiple spring, double loop type was designed. Four f these double loops in parallel gave the equired performance and fit well with he other parts (Fig. 4).

Combination of the Fundamental Regulator Components for Most Efficient Operation

Perhaps the most important design onsideration had to do with the reliability of the mechanism which transmits olenoid force to the carbon stack. A ypical hinged-type relay armature was hosen as the most reliable type. It also nakes possible the use of a bimetallic inge for temperature compensation. The force on the carbon stack was taken t right angles to the armature movement o conserve space and increase rigidity. t was found that a heavy, deep flange n the armature assembly was necessary o minimize distortion under load. This lange, made of stainless steel because of ts high modulus of elasticity, also had to e non-magnetic to prevent flux leakage round the air gap. A reinforcing plate vas brazed and riveted to the back to nake it more rigid.

The second design consideration had o do with the dissipation of heat enerated inside the regulator box. To olve this problem the regulator was astened directly to the stack housing vhich in turn was mounted on an outside eat radiator (Fig. 5). Both the stack ousing and the radiator were made of luminum for good heat conduction. The arbon stack was enclosed in a high hermal conductivity ceramic tube to nprove heat dissipation from this component. The aluminum parts inside the egulator box were left bare to decrease adiation. On the outside they were ainted on high capacity models to nprove radiation. Mechanical fits beween the carbon stack, ceramic tube, nd stack housing were held as close as possible to improve heat conduction. Temperature is the limiting factor in carbon stack rating, since carbon sublimates at approximately 650°F in air.

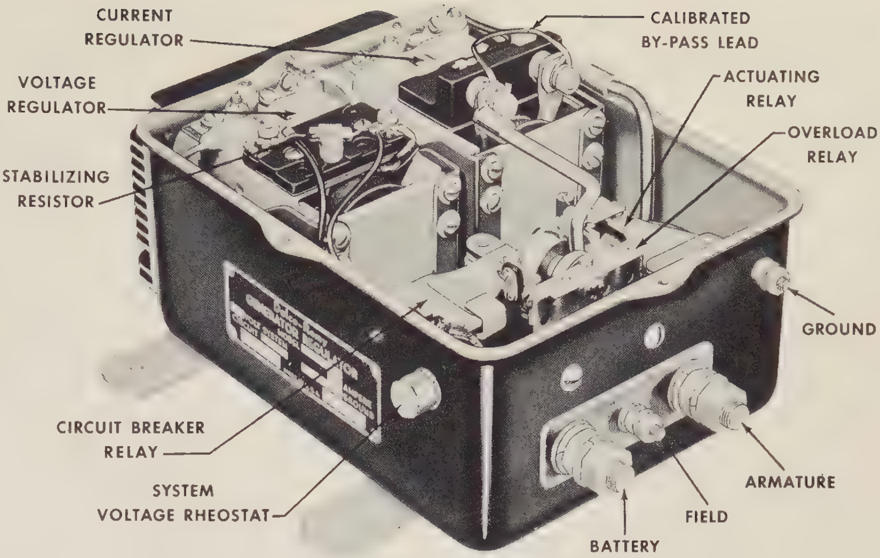

Fig. 7—This three-quarter view of the carbon pile generator-regulator shows the essential components and manner of combination for operating efficiency.

The location of the spring bias, dash pot, terminals, and adjusting mechanisms were pretty well determined by the stack and magnet arrangement. Air gap and operating voltage adjustments are readily accessible on one side of the unit, and the stack may easily be removed for inspection or replacement from the same side.

Construction of Working Models

With the basic layout established the next step was to build working models to test the overall design before considering other details and refinements. Except for minor changes to improve the rigidity of the U-frame and armature, the basic design proved satisfactory. However, considerable experimentation was required on the spring bias to obtain the most satisfactory match with the magnet (Fig. 6).

While the new regulator was quite insensitive to adjustment, it did have a tendency to be unstable on some generators. Its low frictional characteristics made for good regulation, but this also meant that certain natural frequencies in generator output might be "tuned-in" by the regulator and result in violent oscillation of generator output. Numerous damping schemes were considered, but to make one system which would be effective for both voltage and current regulation on all generators, an oil dash pot using silicone fluid was selected.

Case Design

Satisfactory laboratory performance of the basic regulator design opened the way for the next step which was to combine the voltage regulator, current regulator, and two cutout relays in a suitable container. The four units fit reasonably well into an essentially cubical pressed steel box having an aluminum radiator at one end (Fig. 7). Gaskets were used around the cover and radiator to insure a dust-proof and splash-proof container. A variable resistor in series with the voltage regulator coil circuit provided a means of adjusting voltage on the vehicle to correct for changes in setting or to tailor the system voltage to the exact requirements of the individual operator.

Temperature Compensation

Temperature compensation is essential in all voltage regulators because the resistance of copper wire, the only practical material to use, increases considerably with temperature. This means that an electromagnet, which normally operates at the same ampere turns over the usual operating range of temperature, will operate at a considerably higher voltage when hot. Warm-up variation in regulator coil resistance is 20 per cent to 30 per cent, with an equal change due to climatic differences.

Added to this problem is the fact that lead-acid storage batteries require a

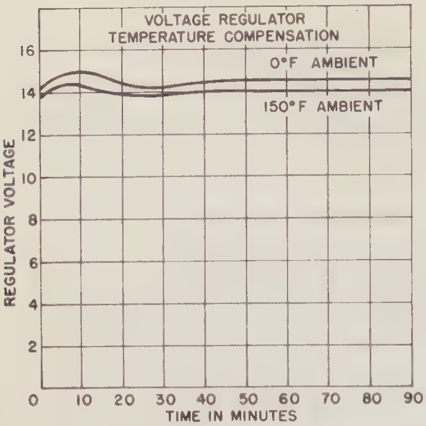

Fig. 8—The graph shows the variation in voltage due to warm-up at two different ambient temperatures with the regulator operating at medium speed and load.

somewhat higher voltage for satisfactory charging when cold. The problem then is to compensate for regulator warm-up and climatic temperature variation, and slightly over-compensate to more nearly meet battery charging requirements.

A number of compensating systems are in use. One commonly used is to attach the movable armature of the regulator with a bimetallic hinge. The hinge bends as it heats up and tends to lower the pull required of the magnet and, hence, its voltage setting. The disadvantage of this device is that it is not thermally close to the coil, so some lag and displacement of compensating effect is obtained.

Another method is to connect a ballast resistor having a very low temperature coefficient in series with the coil. The coil is designed to operate at a fraction of system voltage, so its change in resistance has a small effect on the system voltage. The disadvantages of this system are the loss of power in the ballast and the fact that complete compensation is never possible. A diminishing compensation effect is obtained at increasing power loss as the ballast resistor becomes larger. Since its advantage is extreme reliability, it is often used to do part of the compensating. A negative temperature coefficient resistor would be ideal in this case, but available resistors do not have the required straight line characteristic.

A third method of compensation commonly used is a temperature-sensitive magnetic shunt. Permeability of available material changes from 10 or 20 at 200° F to 10 times that value at 0° F. The magnetic shunt is a reliable means of compensation with good thermal proximity to the coil. Its main disadvantage is that it lowers the field strength of the magnet considerably.

A combination of the above methods was used on the regulator designed by Delco-Remy. Approximately 60 per cent of the compensation was done by a ballast resistor. As much of the remain- ing 40 per cent as feasible was done with a bimetallic hinge. The hinge has two func- tions, and in this case 0.040 in. was about the maximum thickness which could be used and still be sufficiently flexible for the armature movement required. Since this did not entirely compensate the regulator, a small magnetic shunt was used to complete the job. The shunt was made of flat strip stock and pressed over the core on top of the coil. Fig. 8 shows the resulting temperature compensation for warm up at different ambients. The small variation in voltage with ambient temperature is well suited to operators who keep careful check on battery charg- ing requirements and use the external voltage adjustment to compensate for seasonal temperature changes.

Stability

Design of the current regulator pre- sented no additional problems, except that it tended to be more unstable on battery load. The silicone dash pot effec- tively took care of this problem (Fig. 9). A battery load has a capacitive char- acteristic in that an increase in generator excitation produces a large increase in current but a small increase in voltage. This tends to make the voltage control stable, and the current control unstable.

The cutout relays operated satisfac- torily. However, unstable operation of the voltage regulator was especially hard on relays as they fluttered with consid- erable current when the voltage regulator fluttered. Since stable operation was imperative from voltage regulator con- siderations alone, this condition was not considered to be important.

Endurance tests and maximum tem- perature in the carbon stack proved to be satisfactory. The stack and radiator arrangement handled about 60 w at maximum safe operating temperature of the discs. Maximum dissipation on this application was only 30 w.

Service Life Tests

With laboratory tests completed, sev- eral sets of equipment were placed in service for over a year. Periodic inspec- tions of these units were made during this time and a complete performance and tear-down analysis was made at the end of the test. The tests showed the gen- erator interpole windings prone to over- heating, but larger windings and welded connections corrected this difficulty.

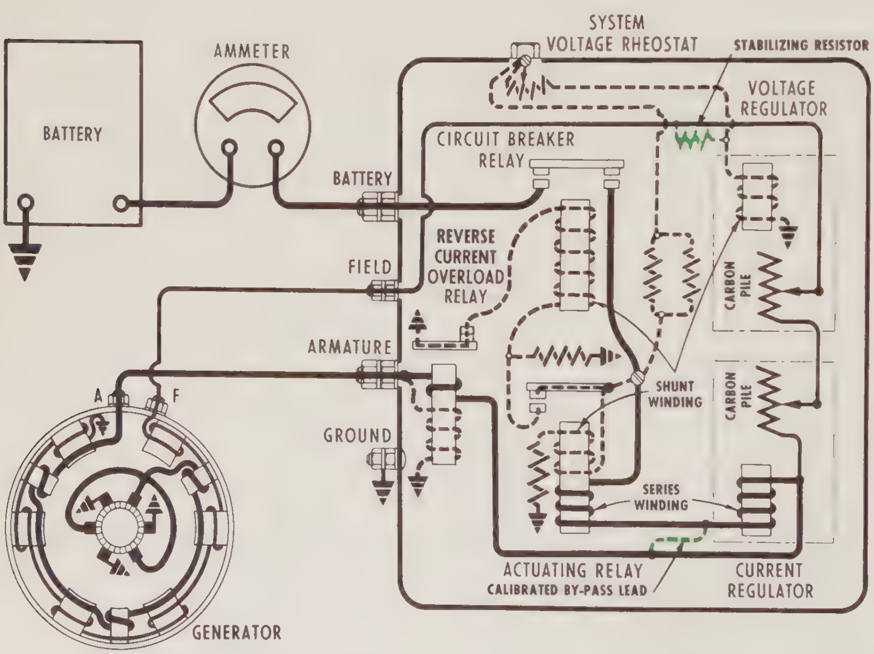

Fig. 9—This circuit diagram shows the basic elements of the charging system. The colored lines show special damping resistors which are used to replace dash pots in applications where the generator is comparatively stable. Some generators are sufficiently stable that no damping is required.

Fig. 10—The 160-ampere carbon pile-type generator shown at left weighs about one-half as much as the conventional 120-ampere generator shown at right.

Commutation was unusually good and brush life excellent. Weight had been reduced from 120 lb to 60 lb which greatly facilitated installation on the engine.

Some difficulty was encountered in maintaining the regulator voltage settings. A slight drop in voltage was noted each month as the test progressed. The source of trouble was creep of the metal in the special calibrating springs. After a considerable study it was found that stresses should be kept below 20 per cent of yield strength in order to avoid objectionable creep. In the original samples four springs approximately 0.4 in. wide were used. This was changed to six springs 0.009 in. thick and approximately 0.6 in. wide with a 60 per cent reduction in stress. In addition, the springs were stressed to 150 per cent of operating load, at 300° F for 24 hr before they were used in order to eliminate all changes in setting due to creep.

Another weakness revealed by the service tests was tarnish of the contact metals at the end of the carbon stack. Silver was the conventional metal to use, since contact with carbon is supposed to keep it free from contamination. Such was not the case, however. While force was high, pressure was light, and sulphide tarnish at the end contacts started to interfere with regulation after several month's use. Gold plating the contacts successfully solved this problem.

Summary

The use of a carbon pile regulator can reduce generator size and improve performance on heavy duty automotive and industrial equipment (Fig. 10). Regulator life and performance can be very good if specifically designed for the job. Applications with high output and low range of control make the best use of inherent carbon pile advantages.

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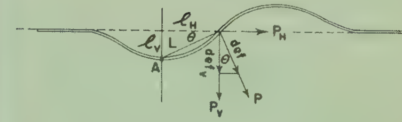
Appendix



Moment about A:

$$M = P_H \times l_v$$

Total stress S at outer fiber for rectangular section:

$$S = S_b + S_t$$

$$S_b = \frac{Mc}{I} = \frac{6P_H l_v}{bh^2}$$

$$l_v = l_{vo} - def_v$$

$$def_v = def \times \cos\theta$$

$$def = \frac{2S_b L^2}{3Eh} \text{ (cantilever formula)}$$

$$l_v = l_{vo} - \left(\frac{2S_b L^2}{3Eh}\right)\cos\theta$$

$$S_b = \frac{6P_H}{bh^2}\left(l_{vo} - \frac{2S_b L^2}{3Eh}\right)\cos\theta$$

$$S_b = \frac{6P_H l_{vo}}{bh^2} - \frac{4P_H S_b L^2\cos\theta}{Ebh^3}$$

$$S_b\left(1 + \frac{4P_H L^2\cos\theta}{Ebh^3}\right) = \frac{6P_H l_{vo}}{bh^2}$$

$$S_b = \frac{6P_H l_{vo}}{bh^2} \div \left(1 + \frac{4P_H L^2\cos\theta}{Ebh^3}\right)$$

$$S = \left[\frac{6P_H l_{vo}}{bh^2} \div \left(1 + \frac{4P_H L^2\cos\theta}{Ebh^3}\right)\right] + S_t$$

where

- S = total stress at outer fiber (psi)
- S_b = bending stress at outer fiber (psi)
- S_t = tensile stress due to load (psi) $= P_H/bh$
- P_H = load (lb)
- l_v = vertical offset (loaded position) in.
- l_{vo} = vertical offset (free position) in.
- b = width of spring (in.)
- h = thickness of spring (in.)
- def = total deflection (in.)
- def_v = vertical deflection (in.)
- L = a length (in.) determined by $\sqrt{l^2_v + \frac{l^2_H}{2}}$
- l_H = span of loop (in.)
- E = modulus of elasticity of steel (psi)
- θ = $\tan^{-1} l_{vo}/l_H$ (approx.).

The Utilization of Sonic Principles for Application to an Automatic Method of Casting Inspection

By MILTON J. DIAMOND
Central
Foundry
Division

An old inspection method—strike the casting—is modernized

The usual methods employed to inspect a casting for cracks or other physical defects depend, to a great degree, on the human element for satisfactory results. The variables connected with the human element, such as operator fatigue or misjudgment, have caused engineers to continually search for a method of casting inspection which would not depend wholly upon the human element for final approval or disapproval of a casting's quality. A recent development by Central Foundry Division engineers is a completely automatic method of high production casting inspection based on the application of electronic instrumentation to the theory behind the foundry industry's oldest method of casting inspection which is, simply stated—defective castings have a different frequency of vibration than good castings.

THROUGH the years, many methods of inspection have been developed to inspect castings for conformance or non-conformance with established specifications. The specific method to employ is dependent upon the inspection standards required. For example, castings requiring inspection for sub-surface defects, in addition to surface defects, require a more exacting method of inspection than do castings which require only an inspection for visible defects or a general conformance to specifications. Also, castings produced on a high production basis require an inspection method which will allow rapid inspection to be made without causing an unnecessary change in production schedules.

During the closing years of World War II, a fluorescent particle inspection method was employed by Central Foundry for the inspection of highly stressed castings made of this Division's pearlitic malleable iron ArmaSteel. The utilization of this method was necessary to meet a higher standard of inspection required for these castings—a standard of inspection which could not be met by the previous inspection method then being used.

The fluorescent particle method of casting inspection, as with all other methods of this type, depends upon a very important variable to obtain satisfactory results—the human element. Many cracks which appear under the black light during the inspection period are not cracks at all but are small folds in the skin of the casting which eventually will be machined off by the customer. These and other false indications of apparent cracks occasionally lead to a high percentage of good castings being rejected. In some instances, a true crack escapes notice because of operator fatigue, misjudgment, or some other reason.

Development of the Sonic Inspecting Method

Although the fluorescent particle inspection method, while having certain limitations, continued to do a good job, Central Foundry engineers still sought an answer to the question—what can be done to inspect castings for defects without having to rely completely on the human element variable? The first step in the final answer to this question came about by chance.

One day the chief inspector was observed demonstrating to a fellow worker that when a defective casting was struck, there was an audible difference in its frequency of vibration when compared with the frequency of an identical casting known to be good. After a brief talk with the inspector and upon further investigation, it was felt that this practice, which represented one of the oldest inspection methods used in the foundry industry to check castings for physical defects, could perhaps be applied to production inspecting techniques.

It was decided to take some good and some defective castings of the same identical shape, weight, hardness, and chemical analysis and measure, by means of electrical instrumentation, their fre-

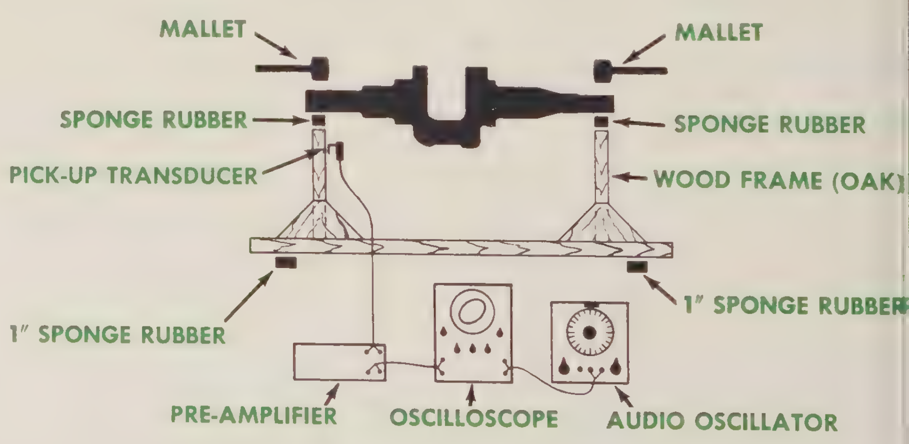


Fig. 1—The electrical instrumentation used in preliminary tests for determining the vibration frequency of the good and the defective castings consisted of a crystal "pick-up" transducer, a pre-amplifier, an oscilloscope, and an audio oscillator. A casting under test, in this case a small size crankshaft, was shocked into mechanical vibration at both of its ends by a leather mallet. The transducer, which was connected to 1/16-in diameter piano wire fastened to an oak frame sounding board, picked up the casting's vibrations and fed them to the pre-amplifier. The output of the pre-amplifier was fed to the horizontal plates of the oscilloscope. The output of the audio oscillator was fed to the vertical plates of the oscilloscope. The audio oscillator was continually tuned until an elliptical *Lissajous figure* appeared on the oscilloscope screen. The frequency of the vibration was then read from the calibrated dial of the audio oscillator.

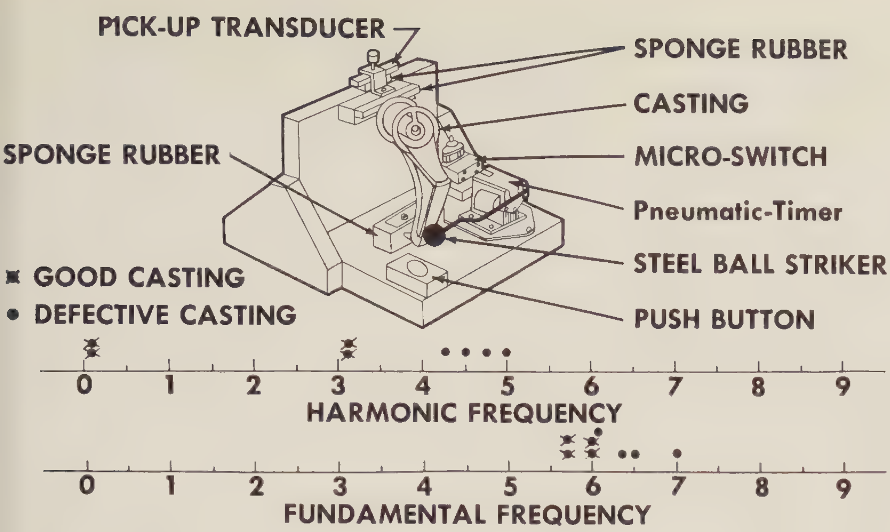


Fig. 2—Preliminary tests for investigating the frequency of the good and the defective castings indicated that a greater separation in frequency occurred when harmonics of the fundamental frequency were used. The test set-up was slightly modified from the original set-up used (Fig. 1). A casting under test, in this case a jack hook for a bumper jack, was shocked into mechanical vibration by a rod-mounted steel ball. The two tests were run with the same castings. The lower scale represents the separation obtained when a casting's fundamental frequency was used. The upper scale represents the results obtained when harmonics of the fundamental frequency were used and points out the greater separation obtained.

quency when struck. The purpose of this basic test was to investigate as accurately as possible whether the good and the defective castings actually had frequencies of vibration which were different and whether there was a sufficient spread in the frequency range between the good and the defective castings.

The instrumentation used for the basic tests consisted of a crystal-type "pick-up" transducer (similar to those used on phonographs), a pre-amplifier, an oscilloscope, and an audio oscillator (Fig. 1). The castings under test, in this case small-size crankshafts, were shocked into mechanical vibration by a leather mallet. The vibrations were picked up by the transducer and then amplified by the pre-amplifier. The output of the pre-amplifier was fed to the horizontal plates of the oscilloscope and the output of the audio oscillator was fed into the vertical plates of the oscilloscope.

A casting under test was continually shocked into vibration, and its frequency of vibration pattern was fed to the oscilloscope screen. The audio oscillator was continually tuned until its frequency pattern and that of the casting formed a single elliptical figure on the oscilloscope screen. (The figure formed is referred to as a *Lissajous figure*, which is a combination of two simple harmonic motions resulting when sinusoidal voltages are applied to both plates of the oscilloscope.) The resulting vibration frequency of the casting was then read from the calibrated dial of the audio oscillator. From the data obtained, the frequencies of various castings were plotted.

After inspecting several groups of castings consisting of castings checked by the fluorescent particle inspection method and castings positively known to be either good or bad, it became readily apparent that it was possible to determine defects in castings by the use of their vibration frequency.

Further tests were run which indicated that on certain types of castings the frequency separation between the good and the defective castings could be increased by using harmonics of the fundamental frequencies. Improved instrumentation was required to show a graphical representation of the greater difference in frequency separation obtained when harmonics were used (Fig. 2).

It became necessary, in a few cases, to find the proper method for suspending a casting in order to obtain desirable frequency separation. For example, a brake pedal casting was suspended in three different positions and the frequency separation results obtained from each position (Fig. 3). For this particular casting, only one method of suspension out of the three gave desirable separation between the good and the defective castings. From these results it became apparent that each casting would have to be studied individually and basic tests run in order to determine the casting's

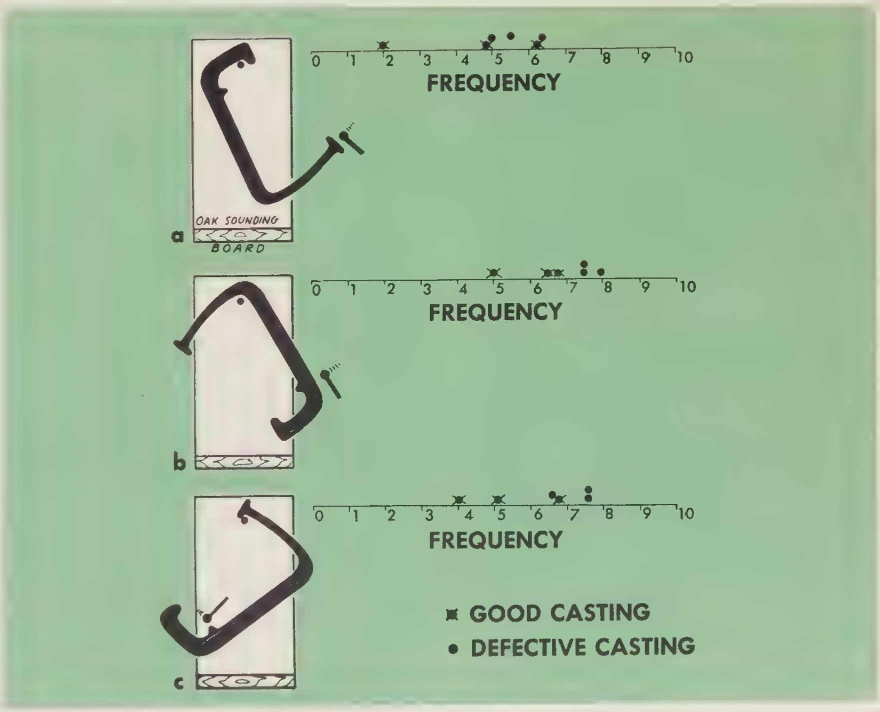


Fig. 3—Preliminary tests indicated that the method of suspending a casting was extremely important if good results in frequency separation were to be obtained. The diagram shows three different methods of suspending a brake pedal casting. For each method three good castings and three defective castings were tested. The same castings were used for each method of suspension. The results obtained from methods (a) and (c) were unsatisfactory as an overlap in frequency separation occurred. The results obtained from method (b) were satisfactory as it gave frequency separation without overlap.

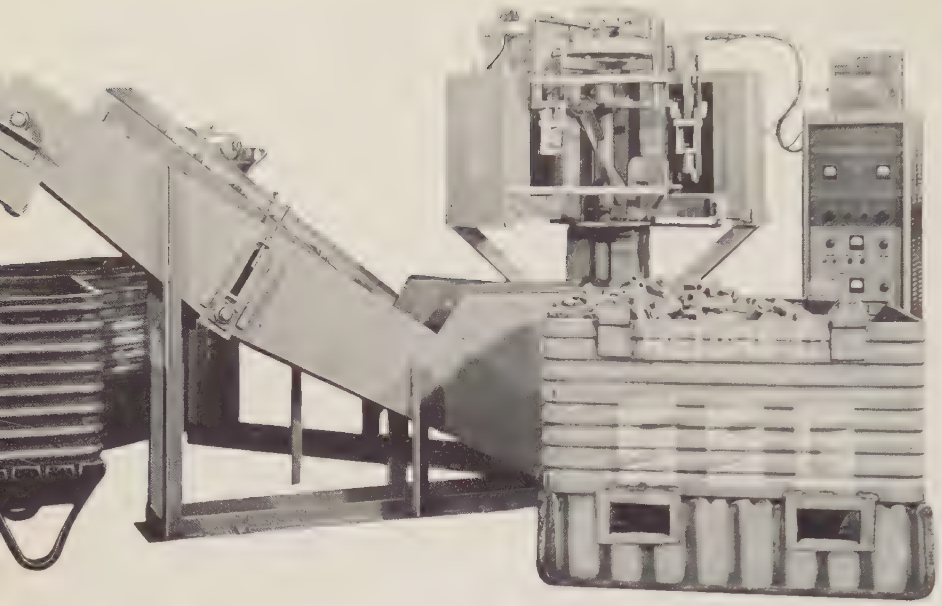


Fig. 4—The sonic inspecting machine utilizes four work stations located 90° apart. The electronic control equipment is mounted in a separate cabinet positioned to the right of the machine. The hopper in the right foreground contains universal joint slip yoke castings ready to be inspected. The conveyor in the left background transfers good castings to a hopper which, when full, is shipped to a customer. The conveyor in the left foreground is used to transfer defective castings to a hopper for removal from the work area.

The services of GM Research Staff's Metallurgical, Physics and Instrumentation, and Instrument Laboratory Departments were enlisted for aid in developing the specialized electronic equipment required.

The heart of the electronic control section was a discriminator which was extremely sensitive to a very few cycles change in frequency. In addition to the discriminator, a limiting amplifier, along with a pre-amplifier and a specially designed microphone, comprised the electronic control section of the device.

It was next decided to use the experimental device on a regular production run. For this purpose a few thousand castings, some good and some defective, were put through the checking device. It was discovered that not only would the device pick out cracked castings but also castings which were known to have interior defects. Further test runs also indicated that certain cold *shuts* or voids, which are formed when molten metal does not run together when poured due to gas formation in the mold and which

frequency range, the correct manner in which it should be suspended, and the best method for picking up its vibration.

The next step in the development program was to use the experience gained thus far toward devising an instrument which would utilize sonic inspecting principles to pass or reject castings automatically. Before this could take place, however, it was necessary to decide what high production casting should warrant the expenditure of time and money required.

It was decided that the universal-joint slip yoke, which was critical from a safety standpoint and required a high standard of inspection, would be the casting inspected for defects by the sonic method and about which an actual production inspecting machine would be built.

Electronic handbooks were consulted to obtain information for the design of the electronic control section of the proposed production machine. A preliminary drawing was made of an electronically-controlled device which appeared feasible for use if certain specialized electronic equipment, not available commercially, could be obtained. The basic design also had provision for automatically spraying good castings with paint.

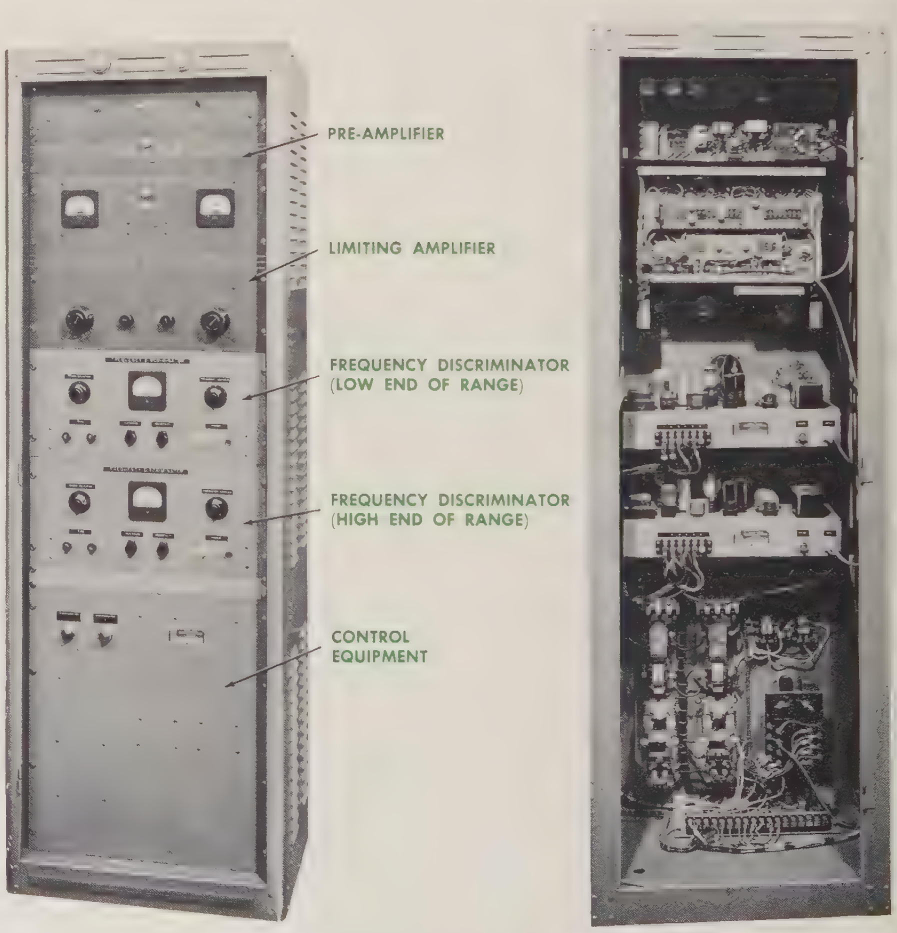


Fig. 5—The electronic equipment used to control sonic inspection is housed in a compact cabinet which is positioned adjacent to the sonic inspecting machine.

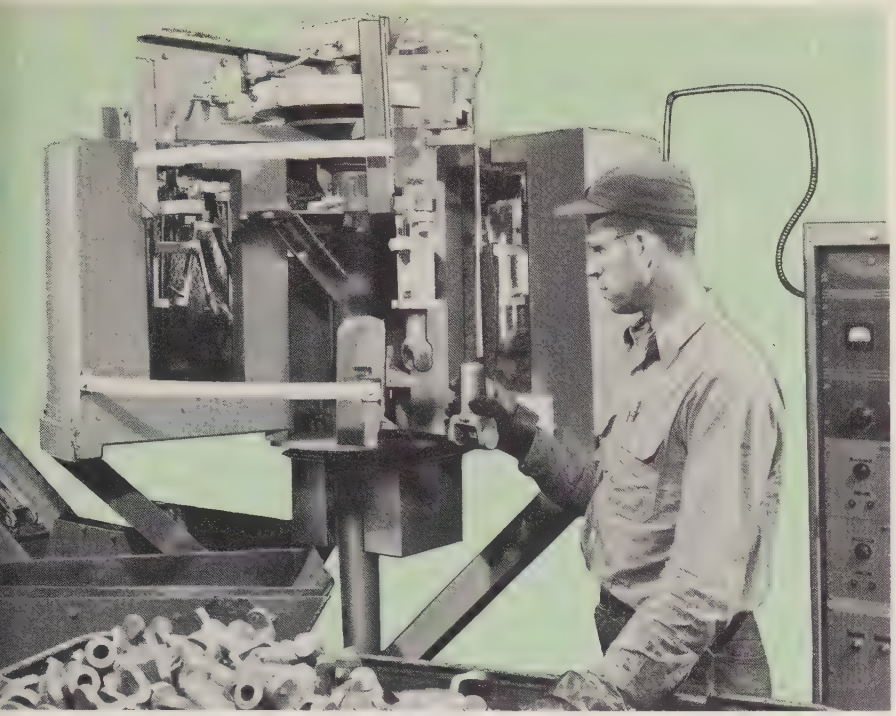


Fig. 6—At the loading station of the sonic inspecting machine an operator positions a universal-joint slip yoke to be inspected into a guide which holds the casting in the correct position until a clamping device passes by and automatically opens and clamps the casting. The device then passes the casting to the ringing station which is shown slightly to the right of the operator's raised hand. In the foreground are castings ready for inspection. At the extreme right is a partial view of the cabinet housing the electronic control equipment. In the left background can be seen the conveyor which transfers good castings to a shipping hopper.

give the appearance of a crack, would cause an increase in frequency. With certain other casting defects the frequency would be the same as a good casting but the decrement would vary.

From these experimental tests it was established that the electronic control section for the production sonic-inspection machine would have to have two discriminators instead of one. One discriminator would be used for the high end of the frequency range and the second discriminator for the low end of the frequency range. An electronic timer would be required, also, to time the decay of the damped vibration produced by the casting.

Sonic Casting Inspection Production Machine

After specifications had been completed for the required electronic equipment the next problem to consider was the design of the necessary mechanical equipment. It was decided to design the machine for sonically inspecting universal-joint slip yoke castings around the "merry-go-round" principle. The machine would have four work stations located 90° apart and, also, a specially designed holder for gripping the casting as it passed through each station.

The design of the completed sonic inspecting machine is such that with a slight adjustment it will handle the three designs of yokes produced by Central Foundry (Fig. 4).

Provision is made that in case any failure occurs in the electronic control section (Fig. 5) all castings will be auto-

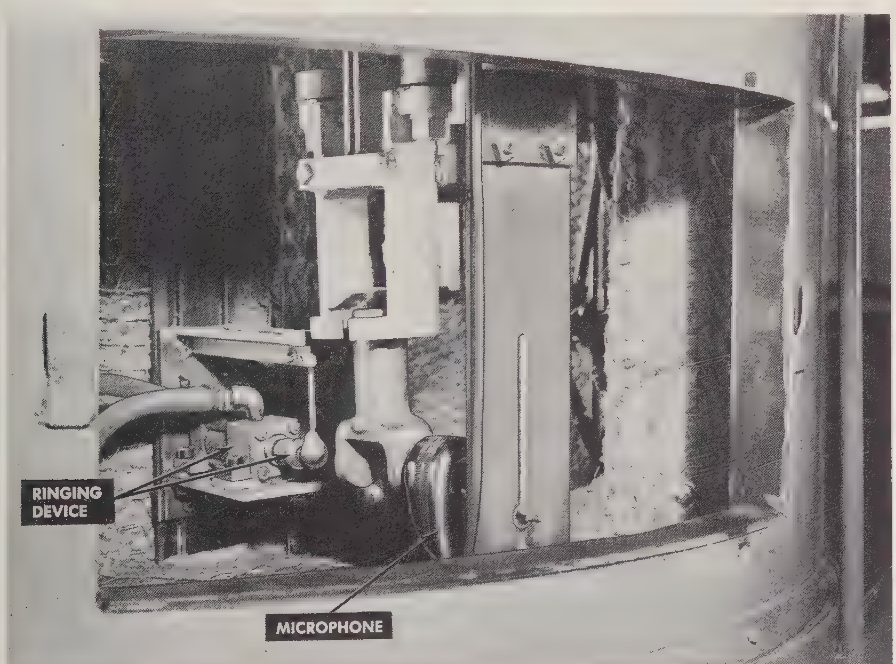


Fig. 7—At the ringing station of the sonic tester a rod-mounted steel ball is actuated by compressed air to set the casting into mechanical vibration. A differential, dynamic-type microphone with special focal properties picks up the vibration for transfer to the electronic control equipment (not shown). A ⅜-in. air gap separates the microphone from the nearest portion of the casting.

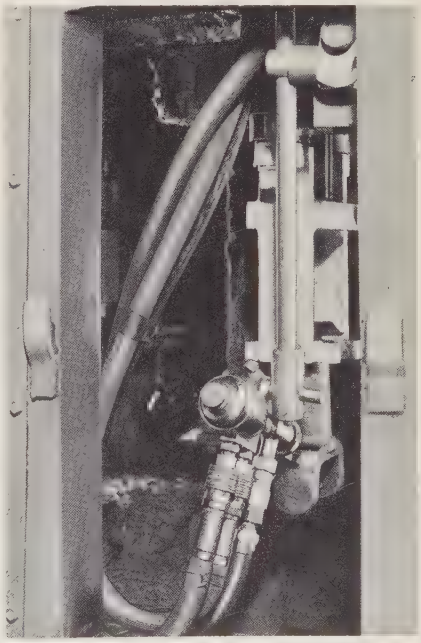


Fig. 8—At the "good unload" station the casting, if its frequency of vibration indicates it to be a good casting, is automatically sprayed with paint and then dropped onto a conveyor for transfer to a shipping hopper.

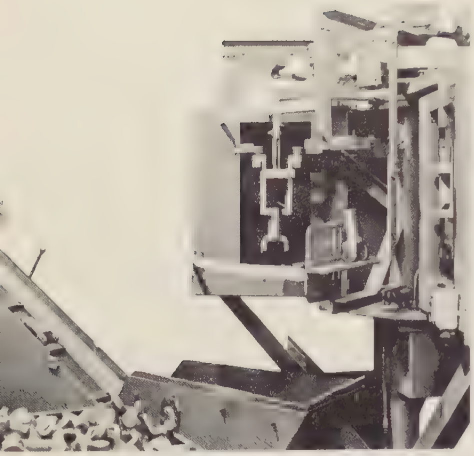


Fig. 9—When a casting whose frequency of vibration indicates it is defective reaches the reject station, the clamping device automatically opens and drops the casting onto a conveyor for transfer to a defective casting hopper. At the right of the clamping device is a casting waiting to be sent through the inspection process. The castings shown in the foreground are waiting to be inspected.

matically rejected and passed into a reject casting hopper.

At the loading station of the machine, an operator places a universal-joint slip yoke casting to be inspected into a guide (Fig. 6). A cam-operated clamping device then passes by the guide and automatically clamps the casting.

The clamping device then moves the casting to the ringing station (Fig. 7). At this station, a steel ball welded to the end of a rod is pneumatically actuated and strikes the casting. The resulting vibration is sent through the air gap a distance of ⅜ in. and is picked up by a dynamic-type microphone having special focal properties. The vibration is then sent, in turn, through the pre-amplifier, limiting amplifier, and finally into the two discriminators which channel the frequency into the proper range. Polarized relays in the discriminators are interconnected in such a manner that if the casting's frequency of vibration is within the "good casting" range a latch relay goes into operation and allows the casting, when it reaches the "good unload" station (Fig. 8), to be automatically sprayed with paint and then dropped onto a conveyor for transfer to a hopper.

If the casting's frequency of vibration does not fall within the "good casting" range, the latch relay does not operate and the casting passes by the "good unload" station. After it passes by this station the clamping device comes in contact with a cam which causes the clamp to open and drop the defective casting onto a conveyor where it is then carried to a rejected casting hopper (Fig. 9).

Temporary Sonic Testing Equipment

In addition to the production machine built for the sonic inspecting of universal-joint slip yoke castings, temporary sonic inspecting set-ups, comprised of a microphone pick-up, pre-amplifier, limiting amplifier, discriminator, and a contact-making micro-ammeter, were used to check gear-blank castings and small size crankshafts. For example, the crankshaft inspection operation consisted merely of actuating the casting into mechanical vibration with a rod-mounted steel ball (Fig. 10). If the casting was good, a small bulb conveniently located would light. If the casting was defective, the bulb would not light.

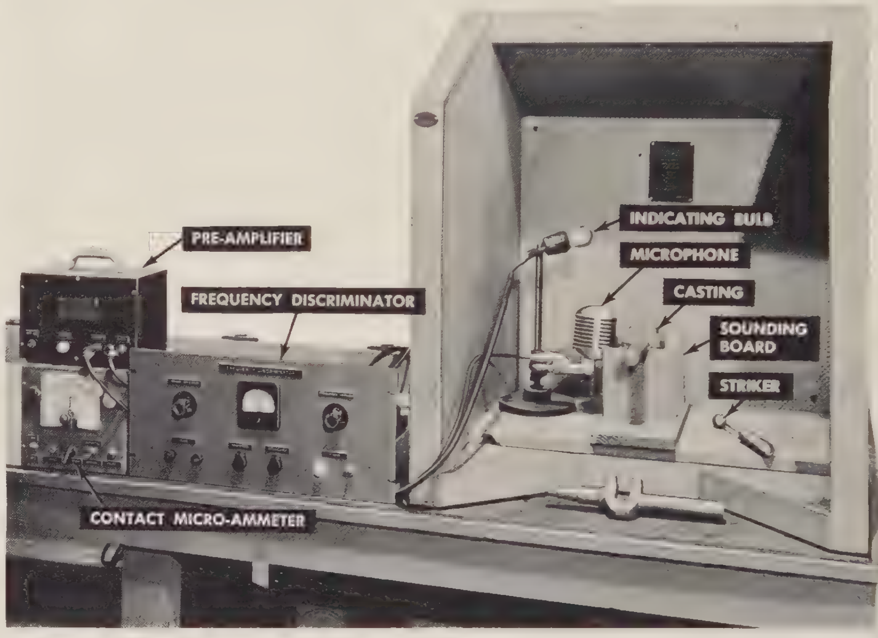


Fig. 10—A manually operated temporary set-up was used to sonically inspect small size crankshafts. The casting, placed in a sound-proof booth, was set into mechanical vibration by the rod-mounted steel ball. A microphone sent the vibration frequency to the electrical instrumentation shown at the left of the booth. This instrumentation consisted of a frequency discriminator, a pre-amplifier, and a contact micro-ammeter. If the casting was defective, the bulb, located inside the booth, would not light. This temporary set-up was capable of sonically inspecting about 500 castings per hour.

Summary

The addition of electronic equipment to the long established practice of inspecting castings for defects by setting them into mechanical vibration and listening to their "ring" has resulted in elimination of the highly variable human element commonly associated with casting inspection methods.

With the increased use of the shell mold casting process by Central Foundry and the closer tolerances which can be realized by the use of this process, as compared to the tolerances possible with conventional green-sand molding, increased use of sonic inspecting methods will be possible. A few castings which have been inspected on an experimental basis and which could be placed on a production inspection basis are brake pedals, jack hooks for bumper jacks, Hydra-Matic automatic transmission gear cases, gear blanks, and small size crankshafts.

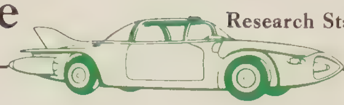
The inspection of castings by the sonic method has resulted in material savings and increased production. It has resulted, also, in giving the customer a casting of higher quality through the elimination of castings which not only have surface defects but also interior defects which, until now, could only be discovered by the use of X-Ray equipment.

Acknowledgement

The author wishes to acknowledge the help of General Motors Research Staff engineers and of his Central Foundry Division colleagues who contributed to the development of the machine used for automatically inspecting castings described in this paper.

Firebird II: New Gas Turbine Powered "Dream Car" Designed for Highway Use

By WILLIAM A. TURUNEN
and JOSEPH B. BIDWELL
General Motors
Research Staff



One of the highlights of GM's annual Motorama is a display of hand-built "dream cars." These "look-ahead" models provide engineers and stylists an opportunity for complete freedom of expression in design and fashion. Among this year's "dream cars" was shown the Firebird II, a gas turbine powered passenger car designed for highway use. Cradled in the sleek four-passenger sports style is an all-new Whirlfire gas turbine engine designed by GM's Research Staff, as well as many other unique features—all developed by a team of General Motors engineers and stylists.

Regeneration improves fuel economy of new gas turbine engine

General Motors has built and successfully tested a new experimental gas turbine passenger car called the Firebird II. The new design, shown publicly for the first time at the General Motors Motorama of 1956 in New York City, was styled as a four-passenger family car for highway use (Fig. 1). However, General Motors has no plans for putting it into production.

The car's new *Whirlfire GT-304* gas turbine engine shows promise of being able to operate at substantially the same economy as today's automotive piston-type engines. The original Firebird, introduced by General Motors two years ago as the first gas turbine powered passenger car developed in the United States, was not designed for highway use. This first car was developed for experimental purposes only to study the possibilities of the gas turbine as an automotive power plant. The Firebird II represents a report to the public on General Motors progress in this study.

The gas turbine engine and the overall chassis design of the Firebird II were developed by the General Motors Research Staff. Other engineering innovations were supplied by GM production Divisions and the GM Engineering Staff. As in the case of the original Firebird, styling was done by GM's Styling Staff.

Whirlfire GT-304 Gas Turbine Engine

The first Whirlfire engine GT-300 (325 hp) and its successor the GT-302 (370 hp) provided GM's research engineers with the experience necessary to develop the latest Whirlfire model (Fig. 2) labeled the GT-304 (200 hp). All of the Whirlfire engines built thus far are of the same basic design; that is, they all have independent gasifier and power sections. The gasifier section of the new GT-304 is essentially a small four-burner jet engine. In no way connected mechanically to the drive train, the gasifier section is simply a shaft with an axial flow turbine wheel on one end and a centrifugal-type air compressor on the other. At rated full power the wheel and compressor turn at 35,000 rpm. Idle speed is 15,000 rpm. Compressor pressure ratio is 3.5 to 1.

The stream of hot exhaust gas from the gasifier section is used to turn the axial-flow turbine wheel in the power section. The power turbine is connected through 7 to 1 reduction gears to an automatic transmission located between the rear wheels of the new turbine-powered passenger car.

One of the greatest limitations of the gas turbine for passenger car use has been low fuel economy. The new Whirlfire GT-304, however, recovers heat in the exhaust gases from the power section as a means of vastly improving this factor. This recovery heat exhanger or regenerator consists of a drum made of metal mesh which is driven approximately

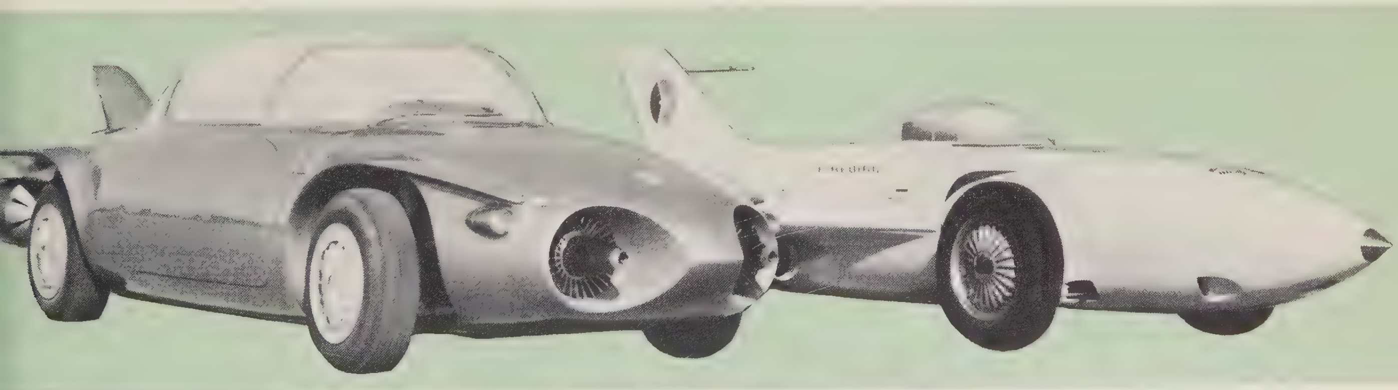


Fig. 1—Contrast between General Motors new experimental gas turbine passenger car Firebird II (left) and its predecessor the Firebird is shown. While the original Firebird (right) was styled as a single-seat model, the Firebird II is designed as a four-passenger family car for highway use. GM has no plans, however, to put the Firebird II into production. The car has a 120 in. wheelbase, is 235 in. long, and 52 in. high to the top of the tail fin. The body is made of the light-weight metal titanium. The Firebird II was shown to the public for the first time in New York City last January at the opening of the General Motors Motorama for 1956. An annual GM show event, the Motorama features a number of hand-built "dream cars", a "Kitchen of Tomorrow", numerous engineering exhibits, and a complete display of GM's passenger cars and other consumer products.

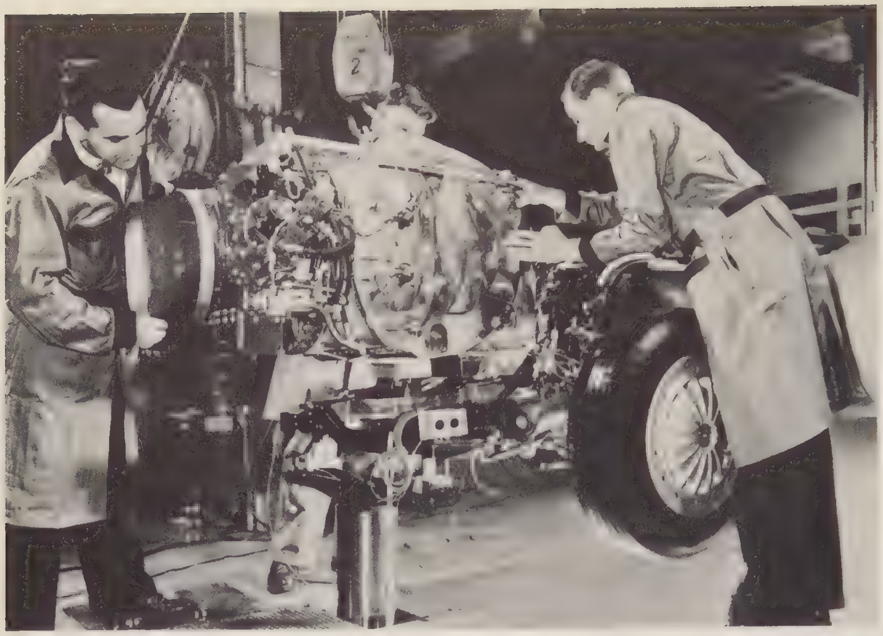


Fig. 2—Developed by GM's Research Staff engineers, the new GT-304 Whirlfire gas turbine engine shown above is being lowered into the chassis of the Firebird II. The engine features independent gasifier and power sections and develops 200 hp. At rated full power the wheel and compressor turn at 35,000 rpm. Idle speed is 15,000 rpm. Compressor pressure ratio is 3.5 to 1.

one-thousandth the speed of the gasifier shaft. The drum rotates first through the hot exhaust gases and then through the relatively cool compressor discharge air carrying heat from the exhaust gas to the incoming air. Over 80 percent of the heat in the exhaust gas is recovered by the regenerator—heat which otherwise would be exhausted to the atmosphere and wasted. Since the temperature of the incoming air is raised mostly by heat supplied from the regenerator, only enough fuel (kerosene) need be burned to raise the pre-heated inlet air up to the normal operating temperature of 1,650° F at the turbine inlet. Tests using the new regenerator show that exhaust temperature can be lowered as much as 1,000° F. Unlike the searing blast from a jèt engine, the exhaust from the Firebird II is just pleasantly warm.

A silencer mounted in the nose of the car effectively muffles engine noise so that the Firebird II is as quiet as most of today's stock cars.

Firebird II Chassis and Body

The Firebird II has a 120-in. wheelbase, is 235 in. long, and 52 in. high to the top of the tail fin. Some of the more unusual features of the chassis are the exhaust ducts located within the side frame members, the transmission, the suspension system which keeps the car level and provides an air-cushioned ride, the all-metal disc brakes, the 12-volt electrical system with its a-c generator, and the central hydraulic system. Unlike the original Firebird, the GT-304 gas turbine engine in the Firebird II is located in front of the driver much like the piston-type engines in today's stock cars (Fig. 3).

A four-passenger sports-car style, the body shell is made of titanium, a lightweight metal of great strength. This is the first time titanium, which presents problems so far as welding and forming are concerned, has been used successfully in an automobile body.

Transmission

The transmission, designed and built by GM's Engineering Staff, is a revolutionary, four-speed, planetary gear and fluid coupling type incorporating an idle cut-out that allows the power turbine to drive accessories in the rear of the vehicle without actually driving the rear wheels. By mounting the transmission between the rear wheels better weight distribution was obtained, a shorter drive mechanism was possible, and the usual hump in the floor of the front passenger compartment was eliminated. Fastened to the frame by means of rubber mounts, the transmission with its integral planetary differential is connected through universal joints to the rear wheels. The inner joint is of the ball and roller type to permit sliding under large torques.

Suspension System

New concepts in automobile suspension are incorporated into the Firebird II. Individual wheel suspension, designed by Research Staff engineers, is combined with the new Delco-Matic Air-Oil Suspension unit, developed by GM's Delco Products Division, to provide smooth, level ride characteristics. Front wheel suspension is of the double-wishbone type, while the rear wheels are mounted separately on short stub axles which are suspended from the frame by swing arms. The transmission, mounted on a frame between the rear wheels, drives each wheel separately through a double universal joint drive shaft. This arrangement has less unsprung mass than the conventional rear axle and differential combination and, thus, transmits less shock to the frame and in turn to the passengers. In addition, a new leveling system, also developed by Delco Products, keeps the car from "bottoming" when loaded, reducing this cause of passenger discomfort at its source.

At each wheel a Delco-Matic Air-Oil Suspension unit replaces the usual shock absorber and spring combination. A cushion of air provides soft spring action and compensates for light or heavy loads by the hydraulic leveling action in the unit. The Delco-Matic unit, about 8½ in. long and 4½ in. in diameter, consists of a small hydraulic piston and cylinder, a rubber diaphragm separator, and the outer steel case. The outer case of the unit is fastened to the car's frame, while the rod of the piston is connected to a wheel suspension member.

Movement of the piston within the hydraulic cylinder displaces oil which forces the rubber separator to expand against the springiness of high-pressure air confined between the separator and the outer steel case. This design provides a highly desirable variable spring rate, smoothing out severe bumps as well as small road irregularities. It likewise gives a variable spring constant, acting as a strong spring when the car is heavily loaded and as a weak spring when lightly loaded. The result is an essentially constant spring frequency that makes the car ride just as smoothly with a driver alone as it does when fully loaded. Leveling is accomplished by varying the quantity of oil in each suspension unit.

Central Hydraulic System

Incorporated in the remarkable Firebird II is a novel central hydraulic system, designed by Saginaw Steering Gear Division. The uniqueness of the system lies in its single, compact, high-pressure hydraulic supply. From this single source is drawn the hydraulic power for the Firebird's Air-Oil Suspension units, power steering, new linear power brake booster, and hydraulic windshield wiper.

The heart of this system is the high pressure hydraulic pump. This pump, in conjunction with accumulators and filter, makes up the hydraulic power supply.

Hydraulic energy is drawn from the accumulators, devices which store hydraulic energy from the pump just as a battery stores electrical energy from the generator. When system pressure drops to 850 lb per sq in., an unloading valve on the pump automatically operates, and the high-pressure pump recharges the accumulators to 1,000 lb per sq in.

The use of accumulators insures a reserve of hydraulic energy instantly available. The accumulators also provide a hydraulic supply with the ignition on but the engine not running. With the ignition off electric check valves are closed to insure that accumulator pressure is maintained.

Of particular interest is Saginaw Steering Gear's new linear brake booster. This device multiplies the braking force, permitting a smooth, quick stop with very light pedal pressure. Since the amount by which the pedal pressure is multiplied is always the same, the linear brake booster maintains a perfect "feel of the road."

Also new are Firebird II's hydraulic windshield wipers. The high, positive-torque motors allow high blade-to-glass loading, resulting in more effective wiping at all vehicle and engine speeds. This unit also provides an automatic alternating power application to free wiper blades frozen to the cowl bar.

Turbo-X Brake

A new all-metal brake, the Turbo-X, provides the Firebird II with smooth, positive, straight-ahead stopping ability. Developed by the Moraine Products Division of General Motors, the new brake operates by squeezing a rotating cast iron disc between pads of metal lining material. The name Turbo-X is derived from the new turbo-cooling feature built into the disc. The cast iron disc rotates with the wheel. When hydraulic pressure is applied to the brake, this disc is squeezed between movable pads of metal lining material on the inboard side of the disc and fixed pads on the outboard side. Stopping power is directly proportional to applied hydraulic pressure.

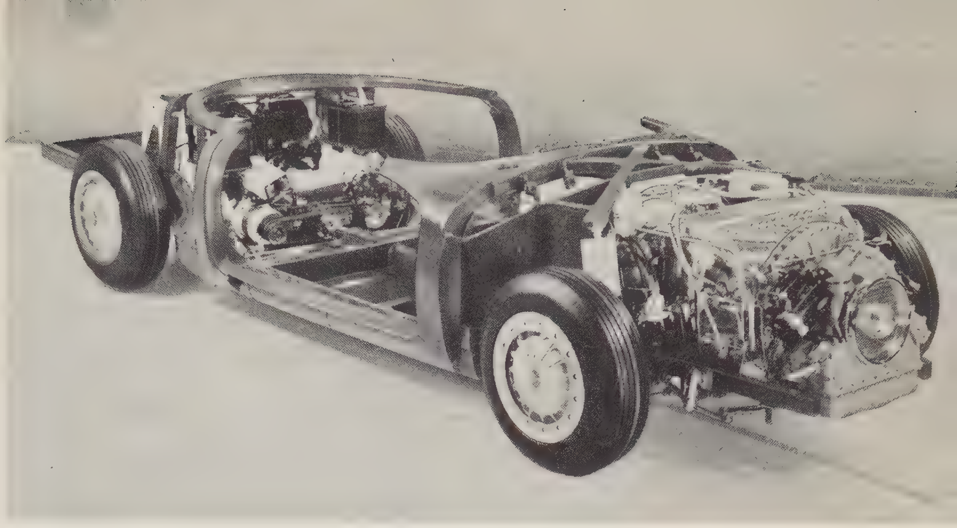


Fig. 3—Some of the more unusual features of the Firebird II chassis are the exhaust ducts located in the side frame members, the rear-mounted transmission, the suspension system which keeps the car level and provides an air cushion ride, the all-metal disc brakes, the 12-volt electrical system with its a-c generator, and the central hydraulic system.

To increase the brake's stopping ability Moraine Products engineers developed a unique turbo-cooling system built into the cast iron disc. The disc has an air space between its braking surfaces with blades that pump air centrifugally through the disc while it is spinning. Heat generated by the braking action is carried away by the air stream and dissipated.

Electrical System

The Firebird II is equipped with a 12-volt electrical system. The starting circuit for the Whirlfire engine is energized by a push button-type switch. The electric starter motor turns over the gasifier section of the turbine. At 4,000 rpm fuel enters the burners automatically and is fired by means of conventional igniter plugs. Once the fuel is ignited, the starter motor continues to assist the turbine until it reaches idle speed (15,000 rpm). At idle speed the starting motor and spark plugs are de-energized automatically, and the car is ready to be driven away.

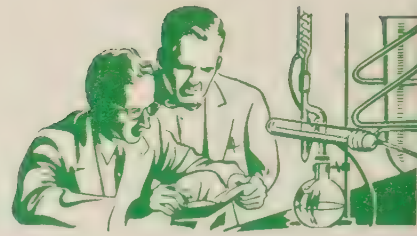
The charging circuit of the Firebird II, developed by Delco-Remy Division, is interesting in that an alternating-current generator is used. Several considerations prompted this choice; first, a-c generators have better voltage-speed characteristics and, thus, can deliver nearly rated output at idle speed; second, much higher output can be obtained from a smaller unit than with d-c equipment; third, the a-c generator output is not handled by a commutator, thus permitting the use of very high currents with a minimum of maintenance. Since the a-c generator's output is 3-phase alternating current, a rectifier is used to convert alternating current to direct current for the car's 12-volt electrical system. Current and voltage regulation is accomplished by an all new transistor-type regulator.

Summary

The Firebird II, third gas turbine powered vehicle developed by General Motors, is in effect a progress report. From an engineering standpoint it is the third stage in an experimental program begun in early 1949 by General Motors Research Staff. Although the Firebird II is strictly an experimental car not intended for production, it shows the progress that has been made in developing the gas turbine automobile during the past two years. At the same time it serves as a showcase and proving ground for other advanced engineering features, for even though responsibility for design and construction of the engine and chassis was assigned to the Research Staff, the project utilized the cooperative efforts of General Motors engineers everywhere. The result is a number of new automotive engineering concepts—all on trial for the first time in the Firebird II.

Notes About Inventions and Inventors

By LEWIS D. BURCH
Patent Section
Central Office Staff



The benefits derived from patents are not limited to the legal rights granted

PATENTS are believed to have indirect values which may have had more to do with industrial expansion in this country than the legal rights which a patent is supposed to convey.

Many a decision to start a new business or a new activity in an old business would never have been made had it not been for the assumption that a patent granted or to be granted would provide a wall behind which to operate for a considerable time without competition. However, the business is started and does prosper, but not because competition does not shortly appear. The patent may never issue or may later appear to be invalid or limited or simply may be found to be unimportant in the development of the business. In the meantime more patents are applied for on improvements that are certain to result, and when granted these patents also may not be used in an effort to prevent competition.

Indirect Values of Patents

Since obtaining a patent is a costly procedure, one may wonder why businesses and individuals continue to apply for patents. The records in the Patent Office in this country show that they do so to a greater extent each year. Perhaps the answer to this can be found in something besides the value of the legal rights granted.

Stimulates Development of Ideas

I once observed an incident which illustrates one way that indirect values may come from patents. A new chief executive was visiting a plant and was making preparations for an important meeting when the chief engineer of the plant called to say that he had a model illustrating a new idea which he would like to show at some convenient time. This executive asked the plant manager to call a meeting of his staff immediately to look at the model. The demonstration which occurred at the meeting was very interesting, but not because of the importance of the idea involved. The thing that was interesting and important was the way this executive handled the demonstration. He watched and listened and asked questions. He also personally asked each person to comment on the idea. If the comment was not favorable, he asked for constructive suggestions. He made the meeting a serious affair, and he told the patent lawyer at the meeting to work with the young engineer responsible for the idea and to do everything he thought advisable to handle the idea properly. This young engineer was impressed by what happened. He evidently had never seen an executive like this and had never had such serious consideration given to one of his ideas. Everyone there was impressed. One result of this meeting was that more patent work was done because people commenced to have more ideas. They saw that ideas were important and that something unusual was done about the ideas.

Obviously this executive was not thinking about legal rights. He was thinking about how to stimulate people to originate ideas. But why couldn't he have held this meeting and done everything that he did without actually instructing the patent lawyer? The fact is that many have tried this approach and it rarely succeeds.

Offers a Satisfying Experience for the Inventor

A patent that is well written and that has good illustrations is an impressive document. It is impressive to receive by mail at your home a copy of a patent that has been issued in your name to the corporation for which you work. Also, it is interesting to see what sometimes happens when a good patent application is prepared on an idea. The inventor often looks at the application, reads it, and studies it in amazement. Prior to this the inventor may not entirely have appreciated just what his idea was or how it might appear when properly described and illustrated. Patents are publications that are kept and preserved in the patent offices and libraries throughout the world. Copies of patents are sold in large numbers to various persons and organizations. Persons other than attorneys and searchers go to patent offices and to libraries to study patents. The inventor may not realize this, but he does know that his idea seems important to him, that it is costing money, and that it must be of value.

The fact is that a person usually does not have just one idea and then decides future effort is not worthwhile, particularly if his first idea was covered by a patent application that was properly handled. This person will become an inventor and will have many more ideas. He will see to it that his employer gets these ideas and that they are not lost nor given to others as being of no value. He will learn that his patents are being sent to others where he is employed, that his immediate superior and the manager of his plant know that they exist. He will discover very likely that his efforts are reflected in promotions and increased compensation.

There are many private inventors who develop ideas on their own resources and efforts and who are supposed generally to do this solely for the possible monetary gain. This may not be entirely true. There are many persons who have a propensity for ideas and for trying to solve problems but who think considerably in advance of their times. Many of these persons certainly could do better for themselves financially. However, the patent system provides these persons with legal justification for doing what they are naturally inclined to do, and sometimes this results in enormous benefits to the public, if not to the inventors. An example of this may

be seen when some important development which is thought to be entirely new and revolutionary goes into production. Patent lawyers will make investigations and prepare patent applications on the idea and will try to cover it completely. Such investigations and the prosecution of the patent applications filed generally will disclose that there is not so much that is new and that much of the idea is disclosed by expired and other prior patents which stand as a bar to the grant of additional patents of similar scope.

Direct Values to Individual and Corporation

The legal rights involved in the grant of patents do have a direct value which often is important to both the individual and the corporation. Some individuals do get ideas that are important to whole industries and are able to license whole industries. If not, they are sometimes able to license one or more corporations in an industry. These licenses sometimes result in important financial returns. Corporations also obtain direct benefits from patents, frequently from trading licenses with other corporations. Sometimes they also grant licenses to obtain financial returns that contribute toward paying the cost of development of an idea, at times even exceeding this cost.

When one considers the number of patents issued each year, it seems remarkable that the patent system functions as well as it does to serve the need of so many different interests and with so little friction from the consequences of the legal rights involved.

On this and the following pages are listed some of the patents granted to General Motors prior to October 31, 1955. The brief patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each patent.

Patents Granted

• **Edward P. Harris,** *Inland Manufacturing Division, Dayton, Ohio, for a Flexible Sealing Strip, No. 2,716,787, issued September 6.* This patent relates to a flexible sealing strip having a longitudinally extending reinforcement made of a rubber-like material having a greater degree of hardness than the remainder of the strip and includes portions which protrude from the strip and act as attachment means when the strip is secured to a door or the like.

• **Edward P. Harris,** *Inland Manufacturing Division, Dayton, Ohio, for a Method of Molding Flexible Sealing Strips, No. 2,719,331, issued October 4.* This patent relates to a method for making elongated flexible rubber-like sealing strips wherein an extensible wire reinforcement is included within the strip. The strip is produced by injecting latex foam into a mold having the reinforcing wire held therein after which the mold and compound are heated to cure the material of the strip.

• **Edward P. Harris,** *Inland Manufacturing Division, Dayton, Ohio, for a Flexible Sealing Strip, No. 2,719,343, issued October 4.* This patent relates to reinforced flexible rubber-like sealing strips such as those used around automotive doors and the like. The strip includes an extensible wire reinforcement having protruding points for attaching the strip to the door.

• **Edward P. Harris,** *Inland Manufacturing Division, Dayton, Ohio, for a Sealing Strip, No. 2.720,685, issued October 18.* This patent relates to a sealing strip for use on automotive doors and the like and having extensible reinforcing means longitudinally thereof, provided with protruding attachment means which extend from the strip in axial planes substantially 90° from one another.

Mr. Harris serves as a project engineer in Inland Manufacturing's Engineering Department and is concerned mainly with foam door seals and car air conditioning. He joined Inland in 1931 as a student in training. From 1938 to 1942 he was technical supervisor at the Inland Clark Plant and from 1942 to 1945 a laboratory supervisor at Eastern Aircraft —a part of General Motors during World War II. Mr. Harris received the M.E. degree from Cornell University in 1931. His technical affiliations include membership in the Society of Automotive Engineers and the American Society for Metals.

• **Willard C. Shaw,** *Delco-Remy Division, Anderson, Indiana, for an Armature Making Apparatus, No. 2,716,803, issued September 6.* This patent deals with a machine for operating on armatures for motors and generators and is directed specifically to a machine for inserting pre-formed armature coils into the armature slots and for subsequently staking the lead ends of the coils into notches of commutator bars.

Mr. Shaw is employed at Delco-Remy as engineer-project on design. He began at this Division in 1939 as a tool making apprentice. In 1943 he was promoted to toolmaker, and in 1945 he became senior designer. He was made foreman of the tool room in 1950, serving until attaining his present position in 1952. He attended Ball State University.

• **Carl A. Stickel,** *Frigidaire Division, Dayton, Ohio, for a Refrigerating Apparatus, No. 2,716,865, issued September 6.* This invention relates to a control system for a two temperature refrigerator where a freezing evaporator cools a frozen food storage compartment, and a higher temperature evaporator connected in series with the freezing evaporator cools an unfrozen food storage compartment. The control system prevents the unfrozen food compartment from being reduced to a freezing or low temperature evaporator.

Mr. Stickel is a patent attorney in the Dayton Office of the General Motors Patent Section. He joined GM in 1930 as a member of the Frigidaire Division Patent Department. Before being admitted to the Ohio Bar in 1932 and the Federal District Court in 1934, he received his M.E. degree in 1927 and LL.B. degree in 1932 from The Ohio State University and University of Dayton, respectively. He was awarded his M.P.L. (Master of Patent Law) degree by University of Dayton in 1934. Several patents in the field of refrigeration and appliances have resulted from his work.

• **James W. Jacobs,** *Frigidaire Division, Dayton, Ohio, for a Refrigerating Apparatus, No. 2,716,867, issued September 6.* This patent provides a refrigerator with a single evaporator for cooling the interior thereof between proper food storage temperatures while periodically defrosting the evaporator to maintain it free of frost.

• **James W. Jacobs,** *Frigidaire Division, Dayton, Ohio, for a Slicing and Storing Device, No. 2,720,700, issued October 18.* This invention relates to a reciprocatable butter slicing and storage device for use

These patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each one.

in refrigerators. The device accommodates different sizes of butter bars and holds the bars against being tilted while manipulating same to cut pats of butter.

• **James W. Jacobs,** *Frigidaire Division, Dayton, Ohio, for a Two Temperature Refrigerating Apparatus, No. 2,720,761, issued October 18.* This invention relates to a siphon which is used to cyclically feed refrigerant from a freezing evaporator to a food storage cooling evaporator. While the siphon is being filled with refrigerant the food storage evaporator is depleted of refrigerant to thereby permit its temperature to increase for defrosting.

Mr. Jacobs serves as a section engineer in the Engineering Department of Frigidaire, where he is currently engaged in the development of electrical controls for refrigeration and automobile air conditioning. Since joining the Frigidaire Patent Department as a draftsman in 1937, Mr. Jacobs has progressed to tracer (1941), to layout man (1943), to project engineer (1946), to senior project engineer (1950), and to his present position (1953). He received the B.S.M.E. degree from University of Dayton in 1954.

• **Everett L. Baugh and DeLoss D. Wallace,** *Cadillac Motor Car Division, Cleveland, Ohio, and Moraine Products Division, Dayton, Ohio, respectively, for a Valve for a Reversible Fluid Pump, No. 2,716,995, issued September 6.* This patent relates to a control valve positioned between opposite sides of a reversible fluid pump to control the direction of flow to and from the pump and to provide a relief valve against excessive pressure.

Mr. Baugh has served as chief engineer at Cadillac Motor Car's Cleveland Tank Plant since February 1955. In 1941 Mr. Baugh joined Delco Brake Division (which later was merged with Moraine Products) as a junior project engineer in the Engineering Laboratory. He transferred to the Cleveland Tank Plant in 1950 as assistant staff engineer. Mr. Baugh earned the B.M.E. degree in 1938 from The Ohio State University and did graduate study work at Massachusetts Institute of Technology.

Mr. Wallace is a section engineer in Moraine Products' Engineering Department. In 1928, two years after earning the B.M.E. degree from The Ohio State University, he joined Frigidaire Division as a development engineer until 1936. In 1943 he rejoined General Motors at Moraine Products. Patents have been granted in the fields of hydraulic equipment, powder metallurgy, filters, sterilizers, and dishwashers resulting from Mr. Wallace's work. He is a member of the Engineers' Club of Dayton and is a registered professional engineer in the State of Ohio.

• **George A. Brundrett,** *Delco Products Division, Dayton, Ohio, for a Shock Absorber Control Valve, No. 2,717,058 issued September 6.* This patent relates to the piston valving of a shock absorber in which the compression valve is permitted to flex bodily before the valve lifts against the pressure of a retaining spring to give a dual relief.

Mr. Brundrett is senior experimental engineer in the Vehicle Development Group of Chevrolet's Central Office. Mr. Brundrett originally started with Delco Products Division in 1946 as a junior engineer. After promotions to experimental engineer (1949) and senior experimental engineer (1952), he transferred to Chevrolet Central Office as a project engineer in June 1952. He was promoted to his present position in 1954. Mr. Brundrett earned the B.S.M.E. degree from University of Michigan, Ann Arbor, in 1944. He is a member of the S.A.E. The work related to this patent was completed while Mr. Brundrett was connected with Delco Products.

• **Max G. Bales,** *Delco-Remy Division, Anderson, Indiana, for a Distributor Stabilizing Device, No. 2,717,286 issued September 6.* This patent relates to a distributor for an ignition system in which the plate that carries the points is resiliently held relative to the base by a quick release spring.

Mr. Bales has been a staff engineer assigned to military equipment since 1949. After earning the B.S.E.E. degree from Purdue University in 1933, he was employed by Delco-Remy in its Production Department and in early 1934 he was designated as a student engineer. In 1939 he became a junior engineer and in 1942 was promoted to senior engineer. He is a member of the S.A.E. and American Ordnance Association.

• **Millard E. Fry,** *Frigidaire Division, Dayton, Ohio, for a Domestic Appliance, No. 2,717,291 issued September 6.* This patent is for a hydraulic oven thermostat in which a disc-shaped thermostat bulb has one or both walls of bimetal which move together upon heating. This displaces some of the hydraulic liquid therein to augment the hydraulic expansion of the liquid to increase the sensitivity of the thermostat.

• **Millard E. Fry,** *Frigidaire Division, Dayton, Ohio, for Domestic Appliances, No. 2,719,906, issued October 4.* This patent relates to an electric range in which a spring clip is provided for holding the supporting rings for the surface heaters in the openings in the top of the electric range.

Mr. Fry is senior project engineer. He earned the B.S. degree in mechanical engineering from University of Pittsburgh in 1931 where he was a member of Sigma Tau, honorary scientific fraternity. In July 1931 he was employed by Frigidaire as a student-engineer-in-training. He was promoted through research engineer, materials and process engineer, and appliance engineer to his present status.

• **John T. Marvin,** *Delco-Remy Division, Anderson, Indiana, for an Electric Switch, No. 2,717,295, issued September 6.* This patent is directed to a door jamb switch used in connection with an automotive door. The switch closes the circuit when the door is open and opens the circuit when the door is closed. Means are provided for opening the circuit by turning the plunger of the switch when the door is opened. Upon closing of the door the switch is automatically closed.

Mr. Marvin has served since September 1937 as patent attorney in the Dayton office of the Patent Section located at Frigidaire. He handles patents from the Delco-Remy, Inland Manufacturing, and Moraine Products Divisions. He earned the B.S. degree from Case Institute of Technology in 1929 and a degree in chemical engineering from the same school in 1935. Prior to joining GM he was chief engineer at Cleveland Heater Company.

• **George W. Jackson,** *Delco Products Division, Dayton, Ohio, for an Electric Motor Operated Power Transmitting Device, No. 2,717,344, issued September 6.* This patent relates to a control apparatus that is manually adjustable to a plurality of selected positions to regulate the extent of movement of a power mechanism to

automatically stop the power mechanism when it has effected movement to the extent selected by the manual control.

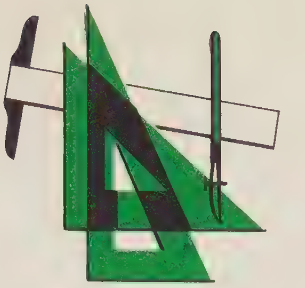
Mr. Jackson is section engineer—research and development—in the Engineering Department of Delco Products. His initial General Motors experience was with the Inland Manufacturing Division from 1937 to 1940. Mr. Jackson joined Delco Products in 1944 as a design engineer and was promoted to his present position in 1947. He earned the B.S.M.E. degree from Purdue University in 1937. Mr. Jackson's work with optical machinery and electro-mechanical actuators and controls has resulted in several patents granted and one paper published on actuator design. His technical affiliations include membership in the S.A.E.

• **Karl Schwartzwalder and Robert W. Smith,** *AC Spark Plug Division, Flint, Michigan, for a Spark Plug with Auxiliary Gap, No. 2,717,438, issued September 13.* This patent relates to the manufacture of spark plugs having an auxiliary spark gap in which the spark plug insulator, upper electrode section, and upper portion of the auxiliary spark gap structure are securely united by a glass seal which is pervious to air so that it can seep into the auxiliary gap.

Mr. Schwartzwalder serves as chief ceramic engineer in the Ceramic Laboratory of AC Spark Plug. His work with ceramics and metal has resulted in 23 patents. He received his B.Cer.E. degree from The Ohio State University in 1930 and his M.S. degree from the same school in 1931. Mr. Schwartzwalder is a member of the S.A.E. and the American Ceramic Society.

Dr. Smith serves as supervisor of physical and metallurgical research at AC Spark Plug. He holds the B.S. degree in physics from University of Chattanooga (1929) and the Ph.D. degree, also in physics, from University of Michigan (1933). Dr. Smith's research in the field of spark plug and electrical instrument design has resulted in nine patents and four published papers on spectrochemical topics. He is a member of the American Society for Metals, A.I.E.E., Optical Society of America, American Association for the Advancement of Science, American Physical Society, and A.S.T.M.

• **Charles A. Chayne and John Dolza,** *GM Engineering Staff, Detroit, Michigan, for a Hydraulic Lash Adjuster, No. 2,718,219,*



issued September 20. This patent covers a hydraulic lash adjuster at the rocker arm pivot which is mounted at the extended end of a stud passing through the rocker from the cylinder head or other fixed supporting portion of the engine.

Mr. Chayne is Vice President of General Motors in charge of the Engineering Staff, located at the GM Technical Center. Mr. Chayne's service with General Motors began in 1930 at Buick Motor Division where he was placed in charge of engine design. He became chief engineer in 1936, a post he occupied until appointed to his present position in 1951. He was graduated from Massachusetts Institute of Technology in 1919, earning the B.S.M.E. degree, and he taught mechanical engineering subjects at the same institution for six years. The Buick straight-eight engine, all-coil-spring suspension, and automatic transmissions were among the projects completed under his direction at Buick. Ten patents covering suspension, steering, frame, and transmission components have resulted from his work.

Mr. Dolza is engineer-in-charge of Power Development at the GM Central Office Engineering Staff, in which capacity he has served since 1945. Much of the work of this group is related to automotive and military engines, air conditioning, and refrigeration. From 1940 to 1945 he was a consulting engineer at Allison Division, engaged in development of various automatic controls for aircraft and turbo-prop engines. Prior to this time Mr. Dolza was associated with Buick Motor Division, starting in 1927 as a draftsman and advancing to assistant chief engineer. He attended the Polytechnico Institute, Turin, Italy, from 1920 to 1926, receiving the M.S.E.E. and M.E. degrees.

• **William E. Brill,** *Cleveland Diesel Engine Division, Cleveland, Ohio, for a Poppet Valve Protection Cup, No. 2,718,220, issued September 20.* This patent covers a poppet valve wherein ovalizing stresses are isolated from a valve seat by an interposed member of softer material having a shoulder in sliding engagement with the valve seat. The interposed member serves to retain the valve head in the event of valve stem breakage.

Mr. Brill is, at present, connected with the Engineering Department of Allison Division. Until recently he had been an engineer at Cleveland Diesel Engine Division since 1933. He earned his engineering degree in 1925 from Case Institute of Technology and he has spent most of his career on Diesel engines. His work in this field has resulted in several granted patents. Mr. Brill has been active in the S.A.E. and in the American Society of Mechanical Engineers.

• **Clayton B. Leach,** *Pontiac Motor Division, Pontiac, Michigan, for a Combustion Chamber, No. 2,718,221, issued September 20.* This invention relates to a highly turbulent combustion chamber for engines, the firing chamber therefor being transversely elongated to receive the valves in the obliquely disposed outer end thereof and positioned across the end of the cylinder to provide oppositely disposed squish areas of different effectiveness.

Mr. Leach is assistant chassis engineer in Pontiac Motor's Engineering Department. His 20-year career with General Motors has been spent at this Division. He was a student engineer from 1935 to 1937, then promoted to draftsman. In 1941 Mr. Leach was promoted to designer, to senior project engineer on engines in 1947, to motor development engineer in 1950, to assistant motor engineer in 1954, and to his present position in 1955. Mr. Leach holds the A.B. degree (1934) from Park College in Missouri, and graduated from General Motors Institute in product engineering in 1937. He has been a member of the S.A.E. since 1939.

• **Edward Jacques and Alfons A. Limberg,** *Fisher Body, Detroit, Michigan, for an Automobile Door Trim, No. 2,718,428, issued September 20.* This is a trim strip which is pivotally mounted on the door window at one upper corner thereof and which cooperates with a stop on the door to cover the opening into which the window is lowered.

Mr. Limberg is engineer-in-charge of the Body-in-white Group in the Experimental and Development Department

of Fisher Body. In 1927 Mr. Limberg joined Fisher Body as a layout man in the Pattern, Jig, and Fixture Layout Department. Four granted patents have resulted from his work with automotive body components. He served for three and one-half years as an apprentice in carriage and automobile bodies and graduated from the Automotive Engineering School in Berlin, Germany. His technical affiliations include membership in the S.A.E., the Engineering Society of Detroit, and the American Society of Body Engineers.

Mr. Jacques serves as plant contact at Fisher Body Division where he was initially employed in 1942 as an experimental welder. He was promoted to metal worker in October 1946, hardware sample worker in October 1948, and to his present position in June 1954. Mr. Jacques is currently working on material control. Previous to his employment at Fisher Body, he worked for 13 years at Cadillac Motor Car Division. This is his first granted patent.

• **Charles J. McDowall,** *Allison Division, Indianapolis, Indiana, for a Mounting and Supporting Structure for Aircraft Gas Turbine Power Plants Having Reduction Gearing, No. 2,718,756, issued September 27.* The structural assembly of a turbo-prop engine including a reduction gear and one or two gas turbines. Rigid shaft housings and struts connect the turbines to the reduction gear. Two external supports are provided at the sides of the reduction gear and one support at the turbine or turbines.

Mr. McDowall serves as chief engineer—Advanced Design and Development Section, Aircraft Engineering Department of Allison. In 1927 he was granted the B.S.M.E. degree from University of Florida. His General Motors career began in 1932 when he was initially employed by Allison as a junior engineer. At present he is in charge of the new engine design at Allison. Mr. McDowall is a member of the Aircraft Engine Division of the S.A.E. and the National Advisory Committee for Aeronautics Subcommittee on Engine Performance and Operation. He has previously served on several committees of the S.A.E. and the N.A.C.A.

• **Gordon E. Holbrook,** *Allison Division, Indianapolis, Indiana, for an Insulating Cover, No. 2,719,099, issued September 27.* The structure patented firmly secures a compressible insulator to a casing during differential thermal expansion of the insulator and casing without compacting the insulator.

Mr. Holbrook serves as assistant chief engineer in the Engineering Department of Allison Division, Indianapolis, Indiana. In 1939 he received the B.S. degree from Massachusetts Institute of Technology. He was originally employed by Allison in 1946 as a project engineer and was promoted to his present position in 1951. Currently Mr. Holbrook is engaged in work on military and commercial power turbine engines and was previously working on the J33 compressor, J33 afterburner, J35 production engines, and production power turbine engines. Mr. Holbrook is a member of the A.S.M.E. and served for three years on the National Advisory Committee for Aeronautics—Powerplant Subcommittee on Compressors.

• **Milton J. Diamond,** *Central Foundry Division, Saginaw, Michigan for an Induction Switching Means, No. 2,719,224, issued September 27.* This invention relates to an electronic triggering circuit for actuating a magnetic hardness testing machine.

Mr. Diamond's biography is published on page 63 of this issue.

• **Walter E. Sargeant and Wesley E. Erwin,** *Research Staff, Detroit, Michigan, for a Rectified Current Supply System, No. 2,719,257, issued September 27.* This patent relates to a regulated rectified current supply system, the output voltage of which is compared with a stabilized reference voltage and the difference voltage supplied to a magnetic amplifier which maintains the rectified output voltage substantially constant.

Mr. Sargeant is a special problems and consultation engineer in the Physics and Instrumentation Department of the Research Staff. Currently he is engaged in an investigation of the possible uses of transistors. His work for the Research Staff has resulted in eight granted patents. Mr. Sargeant received the B.S. degree in electrical engineering from University of Michigan in 1926. He is a member of the Detroit Mathematics Society and the American Physical Society and is an associate member of Sigma Xi.

Mr. Erwin, at the time of his death in 1952, was employed in the Physics and Instrumentation Department of the Research Staff. He received his undergraduate training at University of Cincinnati and the M.S. degree in 1942 from University of Cincinnati, School of Applied Science. Some of Mr. Erwin's past projects at the Research Staff have included work on a silver bearing-bonding process and the use of ultrasonics for non-destructive testing of bonds, the latter leading to the development of the Sonigage for measuring blind-wall thickness.

• **Kenneth C. Kernen, Ralph H. Mitchel, and Raymond E. Schwyn,** *AC Spark Plug Division, Flint, Michigan, for a Connector for Use on High Tension Resistance Cable, No. 2,719,278, issued September 27.* This patent relates to a connector for use on an electrical conductor having a shank with a helical thread thereon that may be threaded into the core of the conductor to provide a mechanical connection.

• **Ralph H. Mitchel and Raymond E. Schwyn,** *AC Spark Plug Division, Flint, Michigan, for Speedometer Temperature Compensation, No. 2,720,603, issued October 11.* This patent pertains principally to a temperature-responsive compensator for magnetic measuring instruments formed from an alloy containing manganese, nickel and iron. An instrument with this compensator provides highly accurate readings over an unusually wide range of temperatures.

• **Ralph H. Mitchel and Raymond E. Schwyn,** *AC Spark Plug Division, Flint, Michigan, for Low-Temperature Compensating Alloy for Magnetic Instruments, No. 2,720,604, issued October 11.* This invention relates to a temperature-responsive compensator for magnetic measuring instruments. The compensator, which is formed from an alloy containing silicon, nickel, iron and manganese, provides the instrument with very accurate readings over an extremely wide range of temperatures.

Mr. Kernen serves as a mechanical engineer in the Manufacturing Development Department of AC Spark Plug. He first joined GM in 1929 as a layout draftsman with Buick Motor Division, and transferred to AC Spark Plug in 1933 as a kiln designer. In April 1955 he assumed his present position. Mr. Kernen was graduated from Michigan State University of Agriculture and Applied Sciences with the B.S. degree in 1920. He is a registered professional engineer in the State of Michigan.

Mr. Mitchel has been with AC Spark 'lug since 1929 when he was employed is a laboratory assistant. He is presently engaged in projects involving electron nicroscopy. Nine patents have resulted rom his previous work in the fields of emperature-sensitive magnetic alloys, lectronic tubes, and engine ignition. Mr. Mitchel earned the B.S.E.E. degree from University of Michigan in 1929.

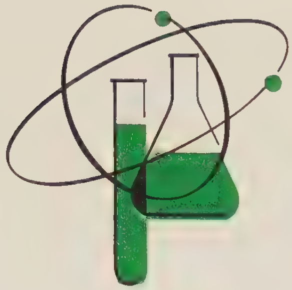
Mr. Schwyn is a senior research netallurgist at AC Spark Plug. He was irst employed as a metallurgist in 1939 ifter being graduated from Michigan itate University of Agriculture and Applied Science with the B.S. and M.S. legrees. At present he is engaged in spark plug electrode alloy development. Previous projects were in the field of temperature-sensitive magnetic materials and he development of electrodes for coldcathode discharge tubes.

• **Melvin F. Penn,** *Frigidaire Division, Dayton, Ohio, for a Lubricant Return in Refrigerating Apparatus, No. 2,719,408, issued October 5.* This is a sealed motorcompressor unit in a refrigerating system wherein the invention resides in preventng refrigerant in the crankcase portion of the unit from flashing into vapor and lischarging lubricating oil out of the crankcase when the unit starts operating.

Mr. Penn is currently engaged in work on commercial air cooled and water cooled condensers and refrigerating units. Some of his previous work concerned lesign and development of rotary and eciprocating compressors and original levelopment of railroad mechanical efrigeration cars.

• **Kenneth E. Snyder,** *Detroit Transmission Division, Ypsilanti, Michigan, for a Servo Mechanism and Associated Valving, No. 2,720,190, issued October 11.* This patent elates to a system for controlling the ydraulic pressures which are supplied o a servo for applying the brake band of a planetary gear unit in an automatic ransmission.

Mr. Snyder serves as senior project engineer at Detroit Transmission Division, Willow Run, Ypsilanti, Michigan. He was originally employed in 1935 at Cadillac Motor Car Division as a project nechanic. In 1941 he transferred to Detroit Transmission and was later pronoted to project engineer assisting in levelopment and testing of improvenents on the Hydra-Matic Transmission.



He was promoted to his present position in 1955. He is currently engaged in work on transmission shift improvement and previously worked on development and testing of tank transmissions, friction reverse, and hydraulic control for the Dual-Range Hydra-Matic. Mr. Snyder's work has resulted in one other patent granted in the field of hydraulic transmissions.

• **Thomas B. Dilworth,** *Electro-Motive Division, LaGrange, Illinois, for a Fluid Circulating System, No. 2,720,194, issued October 11.* This involves a make-up tank for a liquid cooling system having an inclined baffle to increase the pressure on the inlet side of the circulating pump and to remove entrained vapor in the liquid.

Mr. Dilworth serves as an executive engineer in the Engineering Department of Electro-Motive Division, LaGrange, Illinois. He joined Electro-Motive in 1935 as an assembler helper in the Locomotive-Erection Department. His subsequent promotions since then have been to project engineer, senior project engineer, equipment engineer, locomotive engineer, and locomotive section engineer. He was promoted to his present position in 1955. Mr. Dilworth is currently in charge of design and development of all Electro-Motive Division products. He was previously in charge of design and development of special equipment, air brakes, car bodies, trucks, and rebuilds. His work has resulted in the grant of four patents.

• **James C. Holzwarth,** *Research Staff, Detroit, Michigan, for Highly Wear-Resistant Zinc Base Alloy, No. 2,720,459, issued October 11.* This invention relates to a highly wear-resistant zinc base die alloy containing specified amounts of aluminum, copper, magnesium, and dispersed hard particles of nickel-titanium.

Mr. Holzwarth is supervisor of Metallurgical Engineering for the Research Staff. Employed as a junior engineer in 1948 by the Research Staff, he was promoted through the positions of research engineer and senior engineer to his present position in May 1955. Mr. Holzwarth graduated from Purdue University with the B.S. degree in 1945 and received the M.S. degree from the same university in 1948. He served in the United States Navy from December 1942 to June 1946. Mr. Holzwarth is a member of the American Society for Metals. He has had two papers published. This is the first patent resulting from his work, which currently is concerned with corrosion, powder metallurgy, and the Aldip process.

• **John H. Heidorn,** *Frigidaire Division, Dayton, Ohio, for a Two-Temperature Refrigerating Apparatus, No. 2,720,757, issued October 18.* This patent relates to a refrigerator in which two evaporators connected in series serve to maintain two food compartments at different temperatures. The evaporators are so designed that at high room temperatures both evaporators are operated at full capacity, but at low room temperatures a portion of the one evaporator is ineffective.

Mr. Heidorn serves as a section engineer at Frigidaire. He joined the Division in 1938 as a stock tracer and was enrolled during the same year as a cooperative engineering student at General Motors Institute. He was promoted to layout in 1945, to project engineer in 1948, to senior engineer in 1950, and to his present position as section engineer in 1953. His major projects have been concerned with compressor development, and his work has resulted in several granted patents in this field.

• **Edmund F. Schweller,** *Frigidaire Division, Dayton, Ohio, for an Evaporator for Refrigerating Apparatus, No. 2,720,762, issued October 18.* This invention relates to an evaporator for refrigerating systems wherein a conduit coil is mechanically secured in folds of a sheet of metal, and the coil and sheet are then formed into a box-like shape to provide a sharp freezing compartment within the evaporator.

Mr. Schweller is assistant chief engineer of Frigidaire. He was originally employed by this Division as a draftsman and after serving in this position was promoted to project engineer. Subsequent promotions, prior to his present position, included section engineer and manager of the Household Engineering

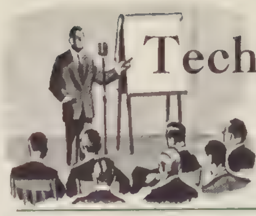
Department. His technical work at Frigidaire has included developmental work on aluminum-foil insulation and on metal shell and one-piece porcelain refrigerators. He is presently concerned with research and future-product development. More than 30 patents have been granted as a result of Mr. Schweller's work in the field of refrigeration and air conditioning.

• **Harvey L. Rittenhouse,** *Euclid Division, Cleveland, Ohio, for Exhaust Heating Semi-Trailer Bodies, No. 2,721,097, issued October 18.* This is a dump body for earth moving vehicles wherein engine exhaust gases are directed through a cavity network in the body to prevent the load from freezing and adhering during cold weather.

Mr. Rittenhouse is director of Inspection and Quality of Euclid Division. He was originally employed by Euclid as assistant chief engineer in 1944 and was promoted to chief engineer in 1946, manager of engineering 1952, and to his present position in 1955. Before coming to General Motors Mr. Rittenhouse worked for General Electric, Bowser Incorporated, and International Harvester. His technical affiliations include membership in the S.A.E., American Society for Quality Control, Construction and Industrial Machinery Technical Committee of the S.A.E., and former membership on the Technical Board. Mr. Rittenhouse has had several papers published, and his work has resulted in the grant of two patents.

• **Lewis A. Taylor,** *Fabricast Division, Bedford, Indiana, for Blow Tube for Shell Molding, No. 2,721,363, issued October 25.* This patent pertains to a shell mold blowing machine having blow tubes which are especially designed to facilitate the blowing of shell molding mixes containing a relatively small amount of resin binder.

Mr. Taylor serves as superintendent in the Inspection Department of Fabricast Division, Bedford, Indiana. Mr. Taylor has been with General Motors for 29 years. He was originally employed by Delco-Remy, Anderson, Indiana, as a student tool maker. Following his apprenticeship he became assistant chief inspector, then chief inspector. Upon transfer to Fabricast he became superintendent of the Iron Foundry and was later promoted to his present position. This is the first patent granted as a result of his work.



Technical Presentations by GM Engineers

Speaking appearances by General Motors engineers are one of the ways in which GM makes available to the public information on current engineering developments. The various appearances include lectures, presentation of technical papers, and participation in panel discussions before interested groups. Listed below are some of the recent speaking engagements filled by GM engineers.

Aeronautical

The 6th National Conference on Standards at Washington, D. C. on October 25 was the occasion for a talk by **C. E. Mines,** chief of engineering services in the Aircraft Engines Operations of Allison Division. Mr. Mines discussed "Cooperative Aeronautical Standards."

At the Student Section and Central Illinois Section of the Society of Automotive Engineers, Urbana, Illinois, on November 2, **William B. Seaver** gave a talk entitled "The Allison T56 Turbo-Prop Aircraft Engine." Mr. Seaver serves as project head on the committee of the T56 engine and power turbine engineering in the Aircraft Engines Operations of Allison Division.

Automotive

"Use of the Hydra-Matic Transmission in Trucks" was the title of a talk presented by **Thomas E. Dolan** for the American Society of Engineers at Berkley Hotel, Montreal, Quebec, Canada, on October 21. Mr. Dolan serves as staff engineer in the Military and Truck Department of Detroit Transmission Division.

"Reminiscences of Progress" was the title of a speech delivered by **M. Olley** on November 2 before the Akron Council of Engineering and Scientific Societies at Akron, Ohio. Mr. Olley serves as special assistant to the chief engineer in charge of Suspension Development in the Research and Development Department of Chevrolet Motor Division.

On November 2 **K. A. Stonex,** head of the Technical Data Department at General Motors Proving Ground, spoke at the 9th Annual Virginia Highway Conference in Lexington, Virginia. The title of his speech was "Development of Safety in Automotive Design."

R. F. Sanders spoke on "The New Chevrolet V-8 Engine" before the Canadian Section of the S.A.E. on November 16 at the Royal York Hotel, Toronto, Canada. Mr. Sanders repeated this talk for the S.A.E., Milwaukee, Wisconsin, on December 2. He serves as chief passenger car chassis design engineer in the Passenger Chassis and Engine Department of Chevrolet Motor Division.

On November 11 **H. K. Gandelot** spoke before a group of graduating Student Adjusters at General Motors Institute on "General Motors Vehicle Engineering and Safety." On December 5 he spoke at a meeting of the Acanthus Club in Detroit, Michigan, on "The Advancement in the Safety of Passenger Cars." Mr. Gandelot is engineer in charge of the Vehicle Safety Section of the GM Engineering Staff.

At a meeting of the Automotive Division of Chemical Specialties Manufacturers Association in the Hotel Lexington, New York, New York, on December 6 **J. G. Coffin** spoke on "Bottled Body Repairs—Easy, Economical and Enduring." Mr. Coffin is assistant materials engineer in the Metallurgy Department of Chevrolet Motor Division.

C. B. Leach, assistant chassis engineer in the Product Engineering Department of Pontiac Motor Division, addressed the Student Chapter of the American Society of Mechanical Engineers, S.A.E., and the American Foundrymen's Society at the University of Illinois, Urbana, Illinois, on December 7. The title of his talk was "Some Practical Aspects of Automotive Design."

"Power Steering Systems" was the title of a talk presented by **C. W. Lincoln**

at a meeting of the American Society of Agricultural Engineers at the Edgewater Beach Hotel, Chicago, Illinois, on December 12. Mr. Lincoln is chief engineer of Saginaw Steering Gear Division.

J. A. Winters, supervisor of sales contact and technical data in the Transmissions Engineering Department of Allison Division, addressed the Student Chapter of the S.A.E. at the University of Wisconsin, Madison, Wisconsin, on December 14. The title of his talk was "Twin Power for Easy Mobility."

On December 15 **C. L. Nelson** addressed the American Standards Association Student Branch, Rensselaer Polytechnic Institute at Troy, New York. "What An Engineer Should Know To Design An Automobile Engine" was the title of his speech. Mr. Nelson serves as resident engineer in the Engineering Department of Chevrolet Motor Division.

"T-3 Guide Safety-Aim Glass Sealed-Beam Units and T-3 Safety Aimer" is the title of a talk and demonstration of the new Guide T-3 Sealed-Beam units and equipment that has been presented to groups throughout the United States by various General Motors speakers. On October 3, 5, and 7, **H.C.Mead,** assistant chief engineer, and **G. R. Broshar,** project engineer of the Engineering Department of Guide Lamp Division, presented this explanation to the States' Approval Officers at Fairfax, Virginia; Tarrytown, New York; and Debham, Massachusetts, respectively. **H. I. Slone,** accessory engineer, and **T. J. Deane,** project engineer in the Engineering Department of Guide Lamp Division, made this presentation before the States' Approval Officers at Memphis, Tennessee, on October 3; Tallahassee, Florida, on October 5; and at Austin, Texas, on October 7. **G. W. Onksen,** chief research engineer, and **R. Arnold,** project engineer in the Engineering Department of Guide Lamp Division, appeared before the States' Approval Officers at Minneapolis, Minnesota, on October 3; Omaha, Nebraska, on October 5; and at Denver, Colorado, on October 7. On October 3, 5, and 7, **R. L. Gross,** research engineer in the Engineering Department of Guide Lamp Division, and **B. L. Booth,** legal advisor of the General Motors Legal Staff, appeared before the States' Approval Officers at Portland, Oregon; Oakland, California; and Salt Lake City, Utah. On December 13 **T. J. Deane** and **C. E. Murphy,** project engineers in the Engineering Department of Guide Lamp Division, made the presentation to the Lions Club at Lapel, Indiana.

Bearings

Before a meeting of the Yale University Student Branch of the S.A.E. on November 9 **Heinz Hanau** presented a talk entitled "Ball Bearings for Aircraft and Turbine Applications." Mr. Hanau is supervisor of Aircraft Projects in the Product Engineering Department of New Departure Division.

On November 9 **A. K. Hoge,** assistant chief chemist in the Product Engineering Department of New Departure Division, addressed the Bristol High School seniors at Bristol, Connecticut. The title of his talk was "Chemical Engineering."

L. D. Cobb, manager of Research and Development in the Product Engineering Department of New Departure Division, appeared at the American Society of Agricultural Engineers Conference in Chicago, Illinois, on December 13. The title of his speech was "Research on Integrally Sealed Bearings." On November 2 and 3 Mr. Cobb addressed the Electric Motor Manufacturers at Hartford, Connecticut. He spoke on "New Departure's Engineering Activities Related to Anticipated Ball Bearing Requirements of the Electric Motor Industry" and also acted as introductory speaker on a panel entitled "Factors Which Influence Ball Bearing Performance in Electric Motors."

On December 13 before the American Society of Agricultural Engineers at Chicago, Illinois, **R. H. Valentine** presented a talk entitled "Advanced Engineering." On November 2 and 3 he acted as introductory speaker on a panel discussion of "Effect of Ball Bearing Characteristics on Electric Motor Performance" at a meeting of the Electric Motor Manufacturers at Hartford, Connecticut. Mr. Valentine is assistant chief engineer in the Product Engineering Department of New Departure Division.

Electronics

"The Skysweeper" was the title of the talk given by **Leonard E. A. Batz** before the Exchange Club at the Hotel Durant, Flint, Michigan, on November 3. Mr. Batz serves as design engineer in the Design and Standards Section at AC Spark Plug Division.

General

On October 20 during the 8th Annual Seminar Workshop of the Photo-reproduction Industry held at Holyoke, Massachusetts, under the auspices of the Technifax Corporation, **Daniel C. Wilkerson** of the General Motors Engineering Staff talked on "The GM Colorline Process." Mr. Wilkerson is an engineer in the Transmission Development Section of the GM Engineering Staff.

At the Saginaw High School, Saginaw, Michigan, on October 21, **Harold G. Sieggreen** addressed the Industrial Education Section of the Michigan Association Conference with a talk entitled "Trends and Opportunities in the Foundry Industry." Mr. Sieggreen is chief engineer of Central Foundry Division.

L. R. Transek appeared before the Newark Chapter of the Retail Sales Engineering Society in Newark, New Jersey, on October 27 discussing "Electric Motors, Where and When." Mr. Transek is sales engineer—distributor salesman in the Sales Department of Delco Products Division.

J. M. Rodgers, project engineer in the Engineering Department of Delco Products Division, and **Werner Valk,** electrical engineer in the same department, appeared at separate sessions of the High Schools Juniors — Career Day, Dayton, Ohio, on October 31. Both discussed "Vocational Guidance in Engineering for High School Juniors."

A Tri-State Area meeting of the Standards Engineers Society on November 17 in Pittsburgh, Pennsylvania, was the occasion for a talk entitled "The Achievement of Uniform Drafting Practice in General Motors" presented by **John W. Smith.** Mr. Smith serves as chief draftsman in the Product Engineering Department of Packard Electric Division.

On December 7 **Kenneth A. Meade,** director of Educational Relations Section, GM Public Relations Staff, spoke on "What is Engineering" before a group of 1,000 high school students at the 21st Annual Engineering and Science Vocational Guidance Meeting sponsored by the Engineering Society of Detroit, Detroit, Michigan.

"Practical Problems of Technical Reporting" was the title of a speech given by **Robert E. Tuttle,** on December 29 at a meeting of the American Business Writers Association in Detroit, Michigan.

Mr. Tuttle is assistant chairman in the English and Psychology Department at General Motors Institute.

Dr. T. A. Boyd, Research Staff consultant, addressed the freshmen and upper classmen of the University of South Carolina on November 1. The titles of his talks were "He Got Off Route 25" and "On Being an Engineer." He also presented "He Got Off Route 25" on December 5 at Tulane University and again on December 15 at the University of Massachusetts. At the Clemson A & M College, South Carolina, on November 2 he addressed the freshmen with a talk entitled "On Being an Engineer."

Industrial Mathematics

John T. Horner, supervisor of engineering calculations in the Aircraft Engines Operations of Allison Division, addressed the Computer Applications Symposium at the Illinois Institute of Technology, Chicago, Illinois, on October 25. The title of his talk was "High Speed Computation of Engine Performance."

"Applications of Mathematics in Industry" was the title of a talk presented by **John D. Hopkins** to the honor students of Penfield Central School, Penfield, New York, on November 16. Mr. Hopkins serves as project engineer in the Engineering Department of Rochester Products Division.

At a meeting of the Indianapolis Section of the American Chemical Society, Indianapolis, Indiana, October 25 **Adolph L. Weiss** presented a talk entitled "Applications of Computers in Science and Engineering." Mr. Weiss serves as assistant supervisor of engineering calculations in the Aircraft Engines Operations of Allison Division.

Manufacturing

P. E. Cartwright, director of Standards, Methods and Plant Layout, Detroit Transmission Division, appeared before the National Industrial Management Society in Chicago, Illinois, on November 10. The title of his talk was "Measured Day Work and its Relationship to a Continuous Cost Reduction Program." Before the Fort Wayne Chapter of American Institute of Industrial Engineering at Fort Wayne, Indiana, on December 5 he presented "Seven Point Program of Cost Reduction at Detroit Transmission Division." On December 9 he presented the same speech at the 30th Air Force Training School at Willow Run, Michigan.

At a meeting of the American Foundrymen's Society in Omaha, Nebraska, on November 14 **L. J. Pedicini** spoke on "Principles of Molding Sand Technology." Mr. Pedicini is senior project engineer in the Foundry of the Process Development Section, GM Manufacturing Staff.

Robert T. Weiser, personnel director at Rochester Products Division, addressed the A.S.M.E. at Chicago, Illinois, on November 14. The title of his talk was "How to Train Engineers for Manufacturing."

"Special Machines—Their Design and Use in a Small Parts Plant" was the subject of **William Bayley's** talk at the A.S.M.E. Diamond Jubilee Meeting in Chicago, Illinois, November 15. Mr. Bayley is in the Manufacturing Development Section of AC Spark Plug Division.

At the same meeting **John A. Mahan** spoke on "A Basic Approach to Progressive Mechanization." Mr. Mahan is an instructor in the Industrial Engineering Department of General Motors Institute.

On November 18 **C. R. Bradlee** participated in a panel discussion on Plastic Working of Metals at the A.S.M.E. Diamond Jubilee Meeting. Mr. Bradlee is project engineer in the Engineering Department of the Process Development Section, GM Manufacturing Staff.

"Role of the Engineer in Manufacturing" was the title of a talk presented by **W. F. Chase** at a meeting of the A.S.M.E. at the University of Detroit, Detroit, Michigan, on December 7. Mr. Chase serves as senior project engineer in the Engineering Department of the Process Development Section, GM Manufacturing Staff.

Metallurgy

On October 19 **Dean K. Hanink**, chief metallurgist in the Metallurgical Department of Allison Division, presented a talk before the American Society for Metals, Metal Congress, at Philadelphia, Pennsylvania. The title of his talk was "A Written Discussion of Paper entitled: 'Effect of Tempering Temperature on Stress Corrosion Cracking and Hydrogen Embrittlement of Martensitic Stainless Steels' by Peter Lillys and A. E. Nehrenberg." On November 2 Mr. Hanink presented a talk entitled "Investment Castings in Aircraft Gas Turbine Engines" at the Investment Casting Institute, Detroit, Michigan.

At a meeting of Foundry Educational Foundation held at the University of Kentucky, Lexington, Kentucky, on November 22 **Fred Carl** showed films on "Heavy and Light Alloys" with general discussion. Mr. Carl is director of Engineering and Inspection of Fabricast Division.

Victor J. Obrig, chief metallurgist in the Engineering Laboratory of Fabricast Division spoke before a meeting of the American Foundry Society at Indianapolis, Indiana, on December 5. His talk was entitled "Melting Practice and Control in our Foundry."

Off-The-Road Vehicles

Speakers from three GM Divisions spoke before the Cleveland Chapter of the S.A.E. in Cleveland, Ohio, on December 12, as a part of a combined presentation on Euclid's new TC-12 Twin Power Crawler Tractor entitled "Twin Power for Easy Mobility." They were **R. C. Williams,** manager of Crawler Tractor Engineering at Euclid Division, **Hugh C. Kirtland,** chief engineer of Applications of the Transmission Engineering Department of Allison Division; and **C. M. Jordan,** chief designer in charge of Special Project Studio No. 4 of General Motors Styling Staff.

At a meeting of the Optimist Club at Cleveland, Ohio, on December 14 **A. S. McClimon** presented a talk entitled "Roads and Road Builders." Mr. McClimon is manager of Sales Development for Euclid Division.

Research

Before the Michigan Section of the American Ceramic Society meeting in Jackson, Michigan, on October 14 **Lloyd Christensen** discussed "How to Increase Level of Creative Activity in Research." Mr. Christensen serves as assistant director in the Production Engineering Department of AC Spark Plug Division.

On October 18 at the Fall Meeting of the Society for Non-Destructive Testing held in Philadelphia **D. E. Clifton** gave a talk on "Non-destructive Testing in the Transportation Industry." Mr. Clifton is an instrumentation engineer at Electro-Motive Division.

Solution to the Previous Problem:

Determine the Stiffness of a Fabricated Steel Supporting Structure for a Diesel Engine

By ROBERT F. ZALOKAR
Cleveland Diesel
Engine Division

Assisted by William H. Lichty
General Motors Institute

Stiffness equals force divided by deflection

Diesel engine vibrations caused by the unbalance of rotating and reciprocating parts in the engine may cause resonance of the engine and its supporting structure within the operating speed range. To insure that this occurrence will have a minimum effect, the designer must calculate the natural frequency of the complete installation in order that resonance with periodic unbalanced forces can be avoided. Before calculating the natural frequency, however, it is first necessary to determine the equivalent mass-elastic system and to calculate the stiffness of the overall supporting structure. The calculations for stiffness are not overly complicated and depend upon a knowledge of engineering mechanics and strength of materials fundamentals. This is the solution to the problem presented in the January-February 1956 issue of the GENERAL MOTORS ENGINEERING JOURNAL. The overall equivalent stiffness for one section of the supporting structure is *47,700 lb per in.*

THE basis for all of the engineer's calculations in a vibration analysis is the breakdown of the structure into equivalent masses and elastic members which will represent most realistically the physical arrangement of the system and which will result in an accurate elastic curve. Fig. 1 shows an exploded view of a typical Diesel engine test-stand installation used by Cleveland Diesel Engine Division. The problem called for the equivalent mass-elastic system of the structure shown in Fig. 1 to be determined and also the overall equivalent stiffness of one section of the engine support members, assuming that a horizontal exciting force of 5,000 lb was distributed evenly along the top of the test base. The

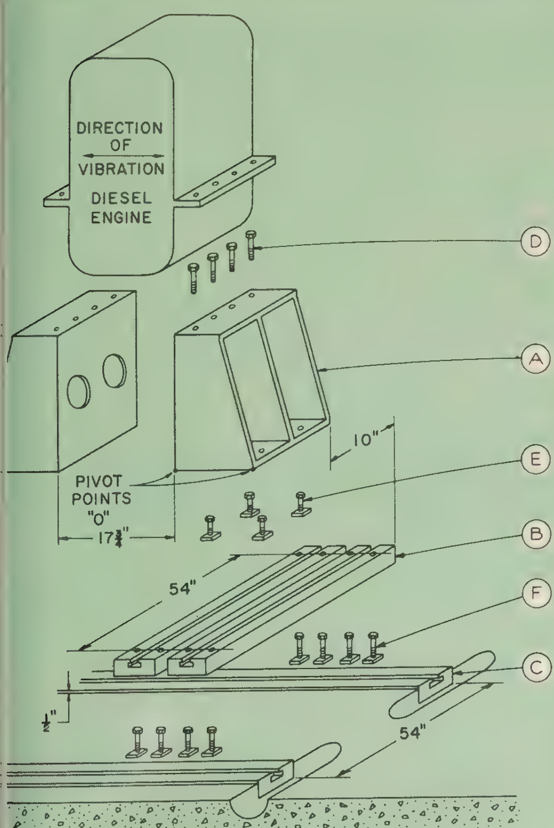


Fig. 1—The Diesel engine and its supporting structure is a complex combination of masses and elastic members which forms the basic structural requirements of a vibration system. The application of a periodic exciting force, produced by the unbalance of moving parts within the engine, can cause motion of the vibration system. In order that resonance with periodic unbalanced forces within the engine will be avoided the design engineer must determine the natural frequency of the complete engine installation. Before this can be accomplished, however, it is necessary to calculate first the stiffness of the supporting structure which consists of two similar test bases *A*, test-base rails *B*, foundation rails *C*, and hold-down bolts *D*, *E*, and *F*.

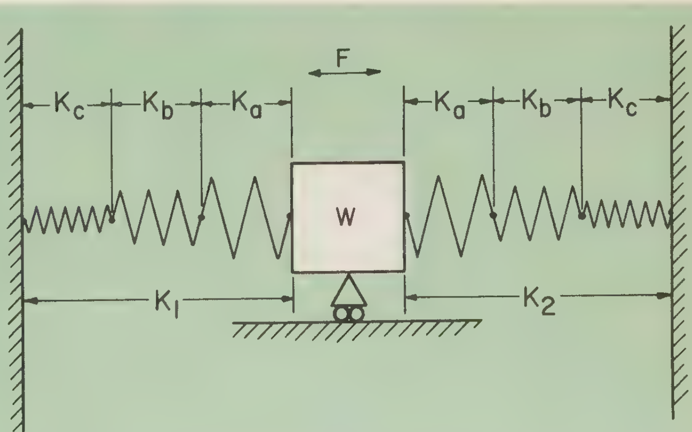


Fig. 2—The Diesel engine and its supporting structure can be represented by a mass-elastic system. *W* represents the weight of the engine and part of the weight of the two test bases. The gravitational effect of *W* does not enter into the calculations for stiffness. The springs K_a represent the stiffness of the test bases. K_b represents the stiffness of the test-base rail hold-down bolts. K_c represents the stiffness of the test-base rails. One set of springs—K_a, K_b, and K_c—each of which is series connected and represents one section of the supporting structure, is equal to an effective stiffness represented by K_1 and K_2.

first step in the solution to the problem is the determination of the mass-elastic system.

Mass-elastic System

Fig. 2 shows the arrangement of the equivalent masses and elastic members which composes the typical fabricated steel supporting structure for a Diesel engine. The weight W represents the weight of the engine and part of the weight of the test bases. The amount of weight to be added due to the test bases depends on their stiffness as compared to the stiffness of the other elastic members. This equivalent weight is supported by two sets of springs, each set containing three identical springs. K_a represents the stiffness of the test base (A in Fig. 1) acting as a cantilever beam. K_b represents the stiffness of the test-base rail hold-down bolts (E in Fig. 1) which are in tension when the test base rocks on pivot points O shown in Fig 1. K_c represents the stiffness of the test-base rails (B in Fig. 1) which act as simply supported beams. One set of these springs (K_a, K_b, and K_c) represents one section of the supporting structure and is series connected to form an equivalent spring designated as K_1.

The overall stiffness of the Diesel engine supporting structure is the total of the individual stiffness values of the structure's one section comprised of one test base, test-base rails, and hold-down bolts.

Stiffness of the Test Base

The test base is assumed to be a cantilever beam fixed at the bottom surface and having a variable moment of inertia I. In order to determine the stiffness of the test base it is first necessary to calculate the deflection Δ at the top of the base. The stiffness for the base will then be equal to the 5,000-lb horizontal exciting force F distributed along the top of the base divided by the base's deflection.

The problem stated that the second area-moment proposition could be used to determine the deflection Δ at the top of the test base. This proposition states that the displacement of the free end of a cantilever beam having a variable moment of inertia I from the tangent to the elastic curve at the fixed end of the beam equals the moment, with respect to the free end, of the area of the part of the bending moment M divided by the moment of inertia I diagram between the free and fixed end divided by the modulus of elasticity of the beam's material.

To find the deflection of the test base by the second area-moment proposition, therefore, it is necessary to divide the base into horizontal sections and then calculate the bending moment M at each section and the moment of inertia I of each section about its own neutral axis. The bending moment M divided by the moment of inertia I is then calculated for each section.

The number of horizontal sections which the test base is divided into is dependent upon the accuracy desired. Fig. 3 shows the test base divided into 13 sections. Table I shows typical calculations necessary to determine the moment of inertia of sections 1, 2, 6, and 12. Table II shows a tabulation for the moment of inertia I, bending moment M, and M/I values for each of the 13 sections. Fig. 4 shows a plot of the I, M, and M/I values versus the test base height. In this figure the actual M/I curve is approximated by the dashed straight-line curve for the purpose of simplification.

Using the approximate M/I curve of Fig. 4, the deflection Δ at the top of the test base can be calculated as follows by the second area-moment proposition (for calculation purposes, the M/I diagram has been broken into squares and triangles):

$$\begin{aligned}\Delta &= (2.4)(0.594)(0.79)+(16.1)(4.81)(3.59)\\&+(46.2)(2.4)(4.39)+(62.3)(6.44)(9.22)\\&+(21.2)(3.22)(10.28)+(83.5)(2.56)(13.92)\\&+(23.0)(1.48)(15.25)+(106.5)(4)(17)\\&+(89.4)(1.5)(19.75)+(17.1)(0.75)(19.5)\\&+(84)(11.5)(26.25)+(5.4)(5.4)(24.3)\\&+(12.7)(1.5)(32.75)/30(10)^6\end{aligned}$$

$$\begin{aligned}\Delta &= (1.12+278+488+3{,}700+701+2{,}980\\&+520+7{,}250+2{,}640+250+25{,}400\\&+755+624)/30(10)^6\end{aligned}$$

$$\Delta = 0.00152 \text{ in.}$$

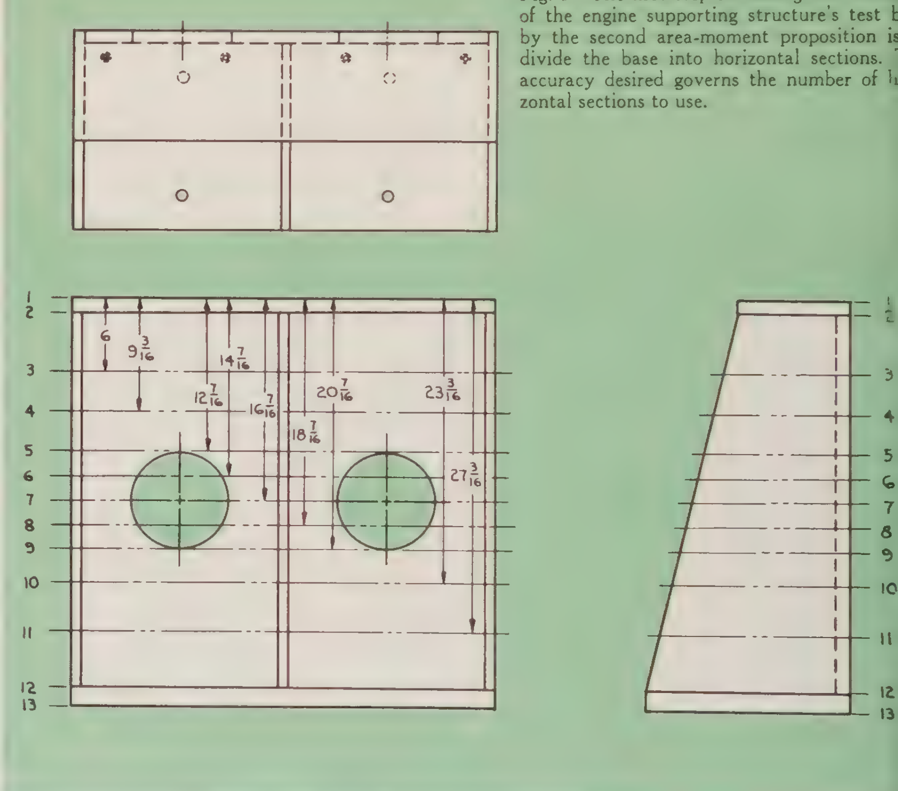


Fig. 3—The first step in finding the deflect of the engine supporting structure's test b by the second area-moment proposition is divide the base into horizontal sections. accuracy desired governs the number of h zontal sections to use.

The stiffness K_a of the test base will be equal to the 5,000-lb horizontal exciting force divided by the deflection or

$$K_a = 5{,}000/0.00152 = 3{,}290{,}000 \text{ lb per in.}$$

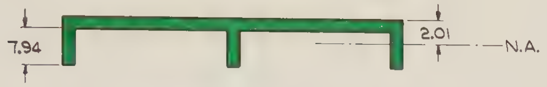
Stiffness of Test-Base Hold-down Bolts

Fig. 5 is a cross sectional view showing the manner in which the test-base rails are fastened to the test base by the ⅞-in. diameter hold-down bolts and the direction of reaction of each hold-down bolt.

SECTION 1

$$I_1 = \frac{34.25 \times \overline{9}^3}{12} = \underline{2\,080 \text{ IN.}^4}$$

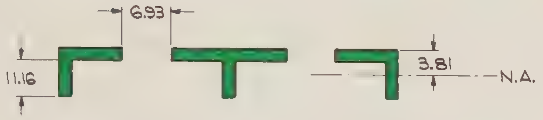
SECTION 2



$$\text{NEUTRAL AXIS} = \frac{(34.25 \times 1.063 \times .531) + (3 \times .75 \times 7.94 \times 5.03)}{(34.25 \times 1.063) + (3 \times .75 \times 7.94)} = \underline{2.01 \text{ IN.}}$$

$$I_2 = \left(\frac{34.25 \times \overline{1.063}^3}{12}\right) + (36.4 \times \overline{1.134}^2) + \left(\frac{3 \times .75 \times \overline{7.94}^3}{12}\right) + (17.86 \times \overline{3.02}^2) = \underline{306.9 \text{ IN.}^4}$$

SECTION 6



$$\text{NEUTRAL AXIS} = \frac{(20.39 \times 1.063 \times .531) + (3 \times .75 \times 11.16 \times 6.64)}{(20.39 \times 1.063) + (3 \times .75 \times 11.16)} = \underline{3.81 \text{ IN.}}$$

$$I_6 = \left(\frac{20.39 \times \overline{1.063}^3}{12}\right) + (21.7 \times \overline{3.28}^2) + \left(\frac{3 \times .75 \times \overline{11.16}^3}{12}\right) + (25.1 \times \overline{2.83}^2) = \underline{697 \text{ IN.}^4}$$

SECTION 12

$$\text{NEUTRAL AXIS} = \frac{19.3 + (3 \times .75 \times 15.44 \times 8.78)}{3.64 + (3 \times .75 \times 15.44)} = \underline{4.55 \text{ IN.}}$$

$$I_{12} = 3.42 + (36.4 \times \overline{4.02}^2) + \left(\frac{3 \times .75 \times \overline{15.44}^3}{12}\right) + (34.8 \times \overline{4.23}^2) = \underline{19.08 \text{ IN.}^4}$$

Table I—The moment of inertia I for each of the 13 horizontal sections into which the test base is divided must be calculated to determine the deflection at the top of the test base. Shown here are typical calculations required to determine the moment of inertia about its own neutral axis for sections 1, 2, 6, and 12.

TABULATION OF M, I, AND M/I VALUES FOR TEST-STAND HORIZONTAL SECTIONS

Section	Distance From Top (in.)	Bending Moment M (in-lb)	Moment of Inertia I (in.^{4})	M/I
1	0	0	2,080	0
2	1 3/16	5,000	2,080	2.4
3	6	29,000	490	59.2
4	9 3/16	45,000	600	75.0
5	12 7/16	61,000	730	83.5
6	14 7/16	71,000	700	101.5
7	16 7/16	81,000	750	108.0
8	18 7/16	91,000	860	106.0
9	20 7/16	101,000	1,130	89.4
10	23 3/16	115,000	1,290	89.1
11	27 3/16	135,000	1,550	87.0
12	32	159,000	1,910	83.3
13	33 1/2	167,500	12,830	13.0

Table II—Tabulation of values for bending moment M, moment of inertia I, and M/I for each of the 13 horizontal sections into which the test base is divided.

Assuming a force F of 5,000 lb distributed horizontally at the top of the base and also that the base and supporting test-base rails are infinitely rigid, the reaction R of each hold-down bolt can be calculated as follows:

$$F(33.5) = R_1L_1 + R_2L_2$$
$$R_1/R_2 = L_1/L_2$$
$$L_1 = 3.75 \text{ in.}$$
$$L_2 = 13.375 \text{ in.}$$
$$F = 5{,}000 \text{ lb.}$$

Therefore,

$$R_1 = 33.5F(L_1/L_1^2 + L_2^2)$$
$$R_2 = 33.5F(L_2/L_1^2 + L_2^2)$$
$$R_1 = 33.5(5{,}000)(3.75/3.75^2 + 13.375^2)$$
$$R_1 = 3{,}260 \text{ lb}$$
$$R_2 = 33.5(5{,}000)(13.375/3.75^2 + 13.375^2)$$
$$R_2 = 11{,}610 \text{ lb.}$$

There are two 7/8-in. diameter hold-down bolts at each end of the test-base rail. The force F on each bolt, therefore, will be

$$F_1 = 3{,}260/2 = 1{,}630 \text{ lb}$$
$$F_2 = 11{,}610/2 = 5{,}805 \text{ lb.}$$

The major diameter of a 7/8-in. diameter bolt is 0.875 in. The stress in the shank of the bolt, therefore, is equal to the force F_2 on the bolt divided by the shank area or

$$\textit{stress in shank} = \frac{5{,}805}{\pi(0.875)^2/4} = 9{,}670 \text{ psi.}$$

The deformation in the shank of the bolt is equal to the stress in the shank times the length of the shank divided by the modulus of elasticity of the steel bolt or

$$\textit{deformation in the shank} = 9{,}670(1.5)/30(10)^6 = 0.000483 \text{ in.}$$

The stress in the threads of the 7/8-in. diameter bolt is equal to the force on the bolt divided by the root area of the thread or

$$\textit{stress in threads} = \frac{5{,}805}{\pi(0.739)^2/4} = 13{,}520 \text{ psi.}$$

The deformation in the threads of the bolts is equal to the stress in the threads times the length of the threaded portion

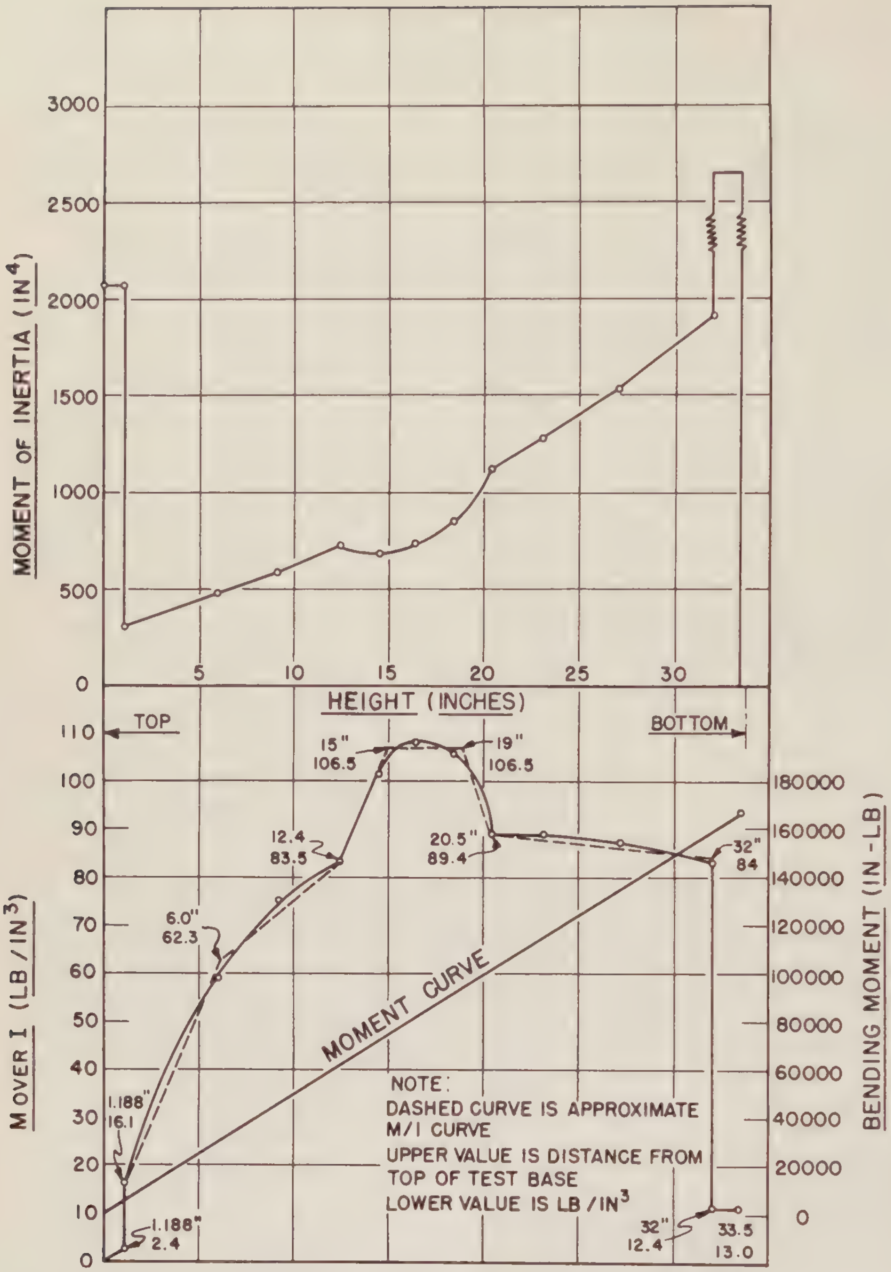


Fig. 4—The values for moment of inertia I, bending moment M, and M/I are plotted for each horizontal section into which the base is divided. This provides the required information to calculate the deflection at the top of the test base by the second area-moment proposition. The actual M/I curve is approximated by the dashed straight line for the purpose of simplification.

divided by the modulus of elasticity of the steel bolt or

deformation in threads

$$= 13{,}520(1)/30(10)^6 = 0.00045 \text{ in.}$$

The total deflection of the ⅞-in. diameter bolt is equal to the deflection in the shank plus the deflection in the threads or 0.000483 in. + 0.00045 in. = 0.000933 in. The corresponding deflection Δ at the top of the test base is equal to the total deflection of the bolt times the height of the test base divided by the distance from the inside edge of the test base to the centerline of the bolt or

deflection at top of test base =

$$\Delta = 0.000933(33.5)/13.375$$
$$= 0.00234 \text{ in.}$$

The stiffness K_b due to the test-base hold-down bolts, therefore, is equal to the force applied to the top of the test base divided by the deflection at the top of the base or

$$K_b = 5{,}000/0.00234 = 2{,}140{,}000 \text{ lb per in.}$$

Stiffness of Test Rails

Fig. 6 shows a detail of the test-base rails which support the test base. The rails act as simply supported beams under a concentrated load. This assumes the most severe loading and end restraint conditions and, therefore, the stiffening effect of the test-base rail hold-down bolts can be neglected.

To calculate the stiffness K_c of the test-base rails it first will be necessary to calculate the deflection at the top of the test base due to the flexibility of the test-base rails. To determine the deflection the force P on each rail, the moment of inertia I of the test rail, and the deflection at the center of the rail under the concentrated load (the worst loading condition) must be calculated as follows:

$$P = 5{,}000(33.5)/16.5 = 10{,}150 \text{ lb}$$

Neutral axis of test rail

$$= \frac{9.19(4)2 - 2(1.25)2.625 - 1(1.125)3.5}{9.19(4) - 2(1.25) - 1(1.25)}$$
$$= 1.9 \text{ in.}$$

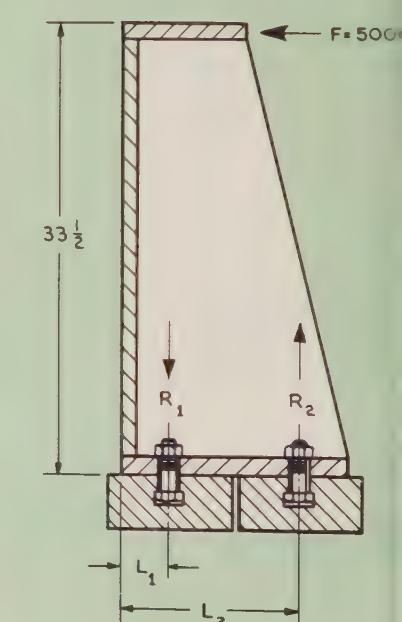
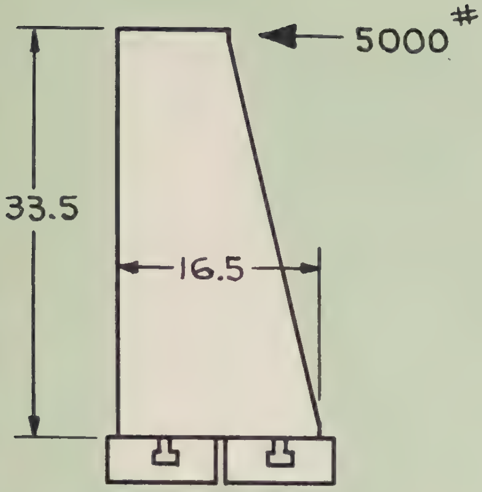


Fig. 5—The test base is fastened to the test-base rails by ⅞ in. diameter bolts whose centerlines are at a distance L_1 and L_2 from the back edge of the base. The horizontal exciting force F of 5,000 lb causes each bolt to have a reaction R_1 and R_2, respectively.



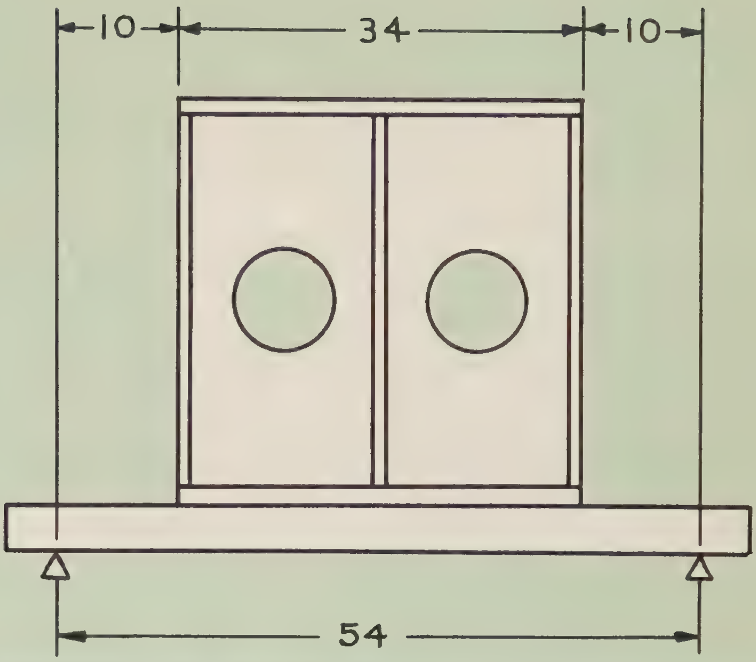


Fig. 6—The test-base rails supporting the test base act as simply supported beams under a concentrated load.

$$I_{rail} = 9.19(4)^3/12 + 36.8(0.1)^2 - 2(1.25)^3/12 - 2.5(0.73)^2 - 1.125(1)^3/12 - 1.125(1.6)^2 = 44.7 \text{ in.}^4$$

The deformation Δ of the test-base rail, which is assumed to be a simply supported beam with the load concentrated at the center, can be calculated by using the following strength of materials formula:

$$\Delta = Pl^3/48EI$$
$$= 10{,}150(54)^3/48(30)(10)^6(44.7)$$
$$\Delta = 0.0249 \text{ in.}$$

Fig. 7 shows an exaggerated view of the deflection at the top of the test base due to the flexibility in the test-base rails. The deflection Δ_t at the top of the test base is

$$\Delta_t = (0.0498)(33.5)/16.5 = 0.1012 \text{ in.}$$

The corresponding stiffness K_c of the test-base rails is

$$K_c = 5{,}000/0.1012 = 49{,}400 \text{ lb per in.}$$

Overall Equivalent Stiffness K_1

K_a, K_b, and K_c represent one set of springs series connected to form an equivalent spring K_1. The overall equivalent stiffness K_1, therefore, of one section of the supporting structure is

$$1/K_1 = 1/K_a + 1/K_b + 1/K_c$$
$$1/K_1 = 1/3.29(10)^6 + 1/2.14(10)^6 + 1/0.049(10)^6$$
$$1/K_1 = 47{,}700 \text{ lb per in.}$$

Summary

There are several observations which can be drawn from the solution to the problem.

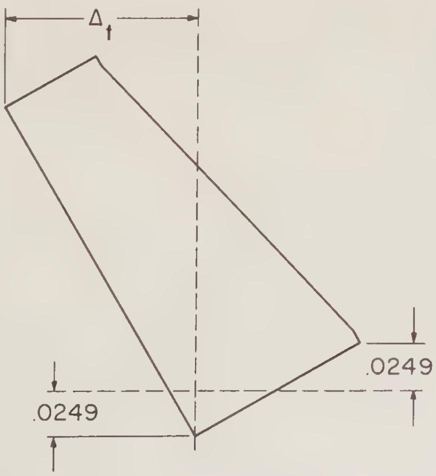


Fig. 7—Because of the flexibility in the test rails, there is a definite amount of deflection at the top of the test base.

- Since the stiffness K is equal to the load F divided by the deflection at the top of the base, any convenient load could have been assumed unless the elastic limit was exceeded.
- Because the test-base rails are so flexible, the weight of the test bases would be substantially added to the weight of the engine.
- The flexibility of the test-base rails is so great that they govern the stiffness of the entire structure. Should there be a need to increase the stiffness of the test-base rails, they could be tied down to an additional foundation rail in the concrete floor between the two foundation rails already present and thereby decrease the unsupported length.

The engine supporting structure used as the basis for this problem was subjected to an actual static loading test. A deflection of 0.121 in. was measured at the top of the test base under a horizontal load of 5,940 lb. This resulted in a stiffness of 49,090 lb per in. which compares very favorably with the analytical equivalent stiffness K_1 of 47,700 lb per in.

A Typical Problem in Engineering:

Determine the Output Torque of a Cam-Operated Indexing Mechanism for an Assembly Machine

By GUY F. SCOTT
Process Development Section

Assisted by Elwood K. Harris
General Motors Institute

When the output torque is known, the mechanical design may proceed

Until a few years ago a rack and pawl sufficed satisfactorily as an indexing mechanism for various types of assembly machines. Then the Geneva mechanism was introduced and revolutionized assembly machine operations in industry. Today, with industry's demand for greater production, it has become necessary for the engineer to design an indexing mechanism better than the Geneva type. It is commonly known that a force applied suddenly can produce stresses and deflections twice as great as the stresses produced by a static force of the same magnitude. The application of inertia forces and their reversal, as is the case when a load is moved from one position to another by the carrier of an assembly machine, create vibrations. These vibrations, which decrease machine efficiency, increase maintenance, and affect product quality, have been minimized to a great degree by the use of properly designed cam-controlled index mechanisms. It becomes the responsibility of the engineer to properly size the cam-controlled indexing mechanism in order that the assembly machine on which it will be used will meet the job requirements.

THE in-line type, wide-track indexing base has particular merit for basic assembly machines* (Fig. 1). Primarily, this base is a steel fabrication. The power source and indexing mechanism, positioned at the bottom of one end, drive a horizontal drive sprocket which moves an endless roller chain around three idler sprockets. The roller chain functions as a conveyor mechanism to move carriers from station to station. The "heart" of the indexing base is the indexing mechanism.

The modern indexing mechanism is cam-operated (Fig. 2). The cam is designed to move a cam follower which, in turn, moves the drive sprocket. There are several types of cams used; the most popular are designed around the following acceleration curves: uniform, sine, cosine, triangular, isosceles, and trapezoid. Some designers make slight modifications to these curves, but basically they attempt to design the cam in such a manner as to move the carrier from one station to the next in a reasonable length of time and with a minimum of "jerk" and vibration.

The design calculations of the cams and the comparison of the merits of each acceleration curve for a cam are very complex and too lengthy to be covered in this problem. In view of this, a uniform acceleration curve cam will

*Nichols, C. A. and Fletcher, W. A., "A Summary of High-Speed Special Assembly Machinery Developed at Delco-Remy", *General Motors Engineering Journal*, Vol. 2, No. 4 (July-August 1955), pp. 2-7.

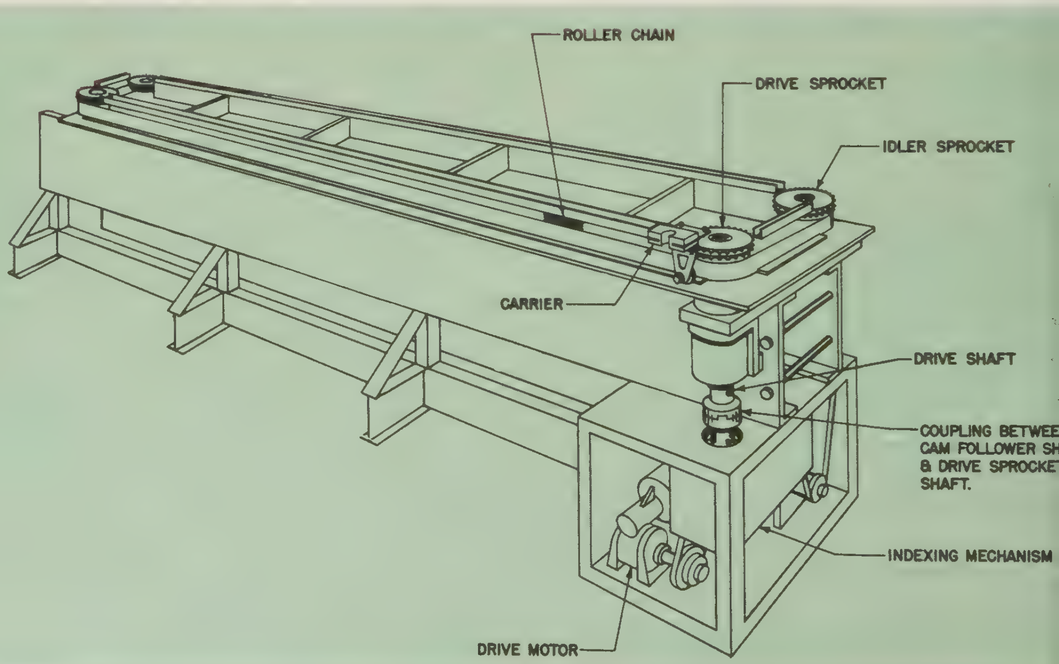


Fig. 1—Proper design of the cam controlled indexing mechanism for an in-line type, wide-track indexing assembly machine is based upon determining first the amount of output torque required by the index mechanism to move the carriers from station to station around the work surface with a minimum of vibration and "jerk".

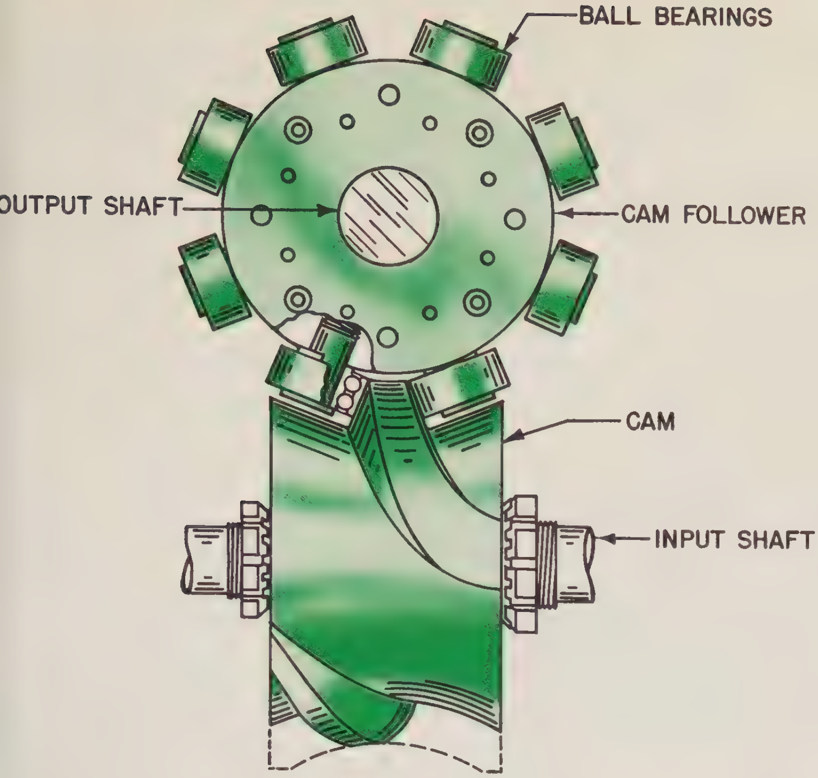


Fig. 2—The most vital part of an indexing assembly machine is the cam-operated indexing mechanism. The cam, which is designed around a specific type of acceleration curve, moves the cam follower. The cam follower, in turn, moves the output or drive shaft to which the drive sprocket is attached.

be used although it may not necessarily have the smoothest acceleration curve (Fig. 3). The calculation of maximum acceleration for a uniform cam, however, is the least complex.

Indexing drives are rated in inch-pounds of output torque. Therefore, the maximum inertia torque required to accelerate and decelerate the inertia of the parts to be indexed must be calculated first. To determine the amount of this required maximum inertia torque T_i, the following equation can be used:

$$T_i = JA$$

where

T_i = maximum inertia torque (in-lb)

J = total polar moment of inertia of carriers, product load, roller chain, and sprockets (in-lb-sec^2)

A = maximum angular acceleration (radians/sec^2).

The maximum angular acceleration A can be determined from the following equation:

$$A = 4\ (2\pi/n)\ (360\ N/a)^2$$

where

n = number of stops of cam follower per complete revolution

a = indexing period. One revolution (360°) of the cam is one index or cycle. The number of these degrees in which the cam follower is moving is the indexing period.

N = cam speed (revolutions per second).

In the formula for maximum angular acceleration A, the number 4 is called the coefficient of maximum acceleration for a uniform acceleration curve. Maximum acceleration formulae for all indexing curves are identical to the above with the exception of the first number. This allows the designer to compare acceleration curves by comparing their coefficients. The acceleration curves previously mentioned have the following acceleration coefficients: sine 6.283, triangular 6 or 12, trapezoid 5.33, cosine 4.935, and isosceles 8.

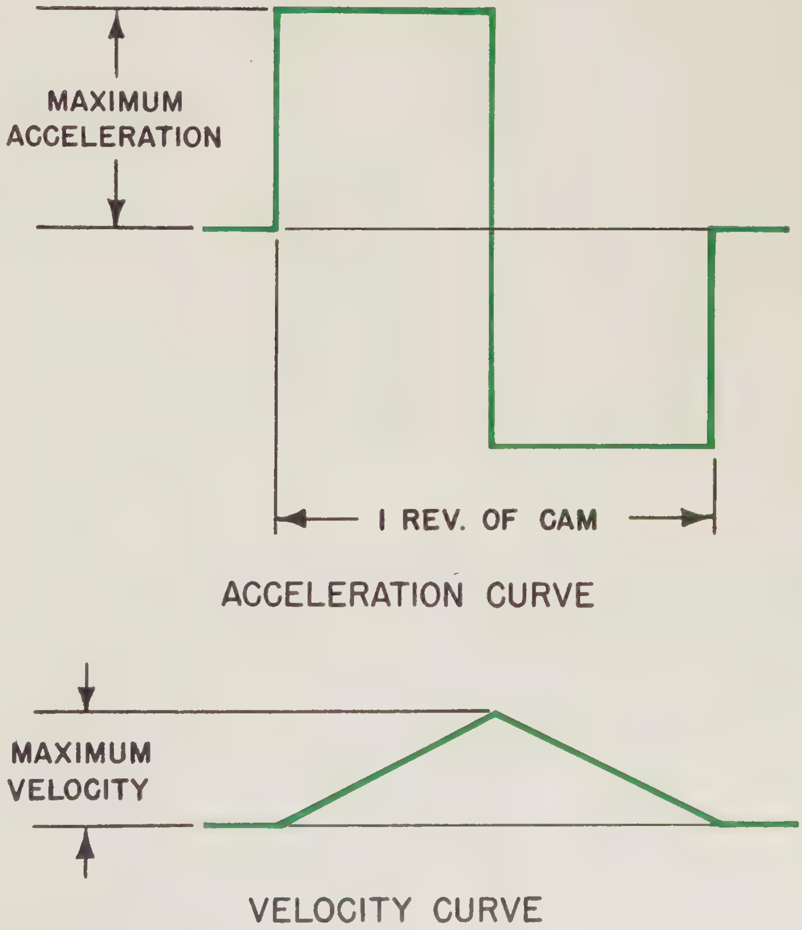


Fig. 3—The cams used in conjunction with an indexing mechanism are usually designed around either uniform, sine, cosine, triangular, isosceles, or trapezoid acceleration curves. The curves shown are for uniform acceleration.

Problem

The problem is to calculate the output torque required by the index mechanism to index 90 carriers between stations located six inches apart. The index time is to be 0.5 seconds. The carriers, weighing 4 lb each including product load, are attached to a $\frac{3}{4}$-in. pitch, double-strand, standard roller-chain which weighs 1.95 lb per ft. The cam follower has 8 rollers and the cam is double pitched. (The cam follower, therefore, makes $\frac{1}{4}$ of a revolution per revolution of the cam.) The cam follower moves through 270° of the cam's revolution. The carriers are anti-friction bearing mounted and have a coefficient of rolling friction of 0.003.

Since the $\frac{3}{4}$-in. pitch roller chain must move 6 in. or 8 pitches while the drive sprocket makes $\frac{1}{4}$ of a revolution, the drive sprocket must have (8 x 4) or 32 teeth. A 32-tooth double sprocket has the following dimensions:

hub diameter = 4 in.
hub projection = 1.409 in.
pitch diameter = 7.652 in.
tooth face = 1.341 in.

The sprockets may be treated as solid cylinders. The inertia of the drive shaft may be neglected.

Since the indexing cam has been designed to minimize vibration, it is necessary that the drive shaft between the drive sprocket and the index cam follower be stiff enough so that it will not be subjected to excessive twist when the torque load is applied. The allowable twist for the drive shaft can be taken as 0.08 degrees per foot. Assuming that a 15-in. long drive shaft is required, what should the shaft diameter be? The solution to the problem will appear in the July-August 1956 issue of the General Motors Engineering Journal.

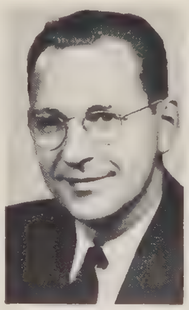
May-June Souvenir Issue Available in Quantity

The May-June issue of the General Motors Engineering Journal will be a special souvenir-type issue in connection with the formal dedication of the new General Motors Technical Center. All of the technical papers and other material in this issue will reflect the kinds of work undertaken at the Technical Center, as well as descriptions of the modern, up-to-date equipment, facilities and architectural features. A portion of the issue will be devoted to full-color reproductions of both exterior and interior views of the Technical Center laboratories and grounds. As with all issues, additional copies of this souvenir issue will be available to educators free on request to:

Educational Relations Section
Public Relations Staff
General Motors Corporation
P. O. Box 177 North End Station
Detroit 2, Michigan

Contributors to March-April 1956 Issue of

GENERAL MOTORS Engineering JOURNAL



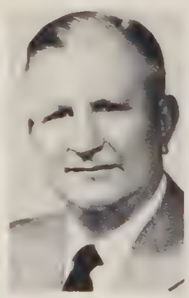
JOSEPH B. BIDWELL, co-contributor of "Firebird II: New Gas Turbine Powered 'Dream Car' Designed for Highway Use," has been head of the Engineering Mechanics Department of the General Motors Research Staff since July 1955.

He began working on the staff of General Motors Research Laboratories as a summer student and became a full-time staff member upon graduation from Brown University with the B.S.M.E. degree in 1942. From July 1944 to January 1946 Mr. Bidwell served in the U. S. Naval Research Laboratory both as a civilian on inactive duty and as an ensign. His work there concerned separation of uranium isotopes.

In 1946 he was promoted to research engineer with the GM Research Laboratories and in 1949 became a senior project engineer. He was appointed assistant head of the Mechanical Development Department in June 1951.

Mr. Bidwell has worked on such technical engineering problems as lubrication, bearings, and fundamental studies concerning friction. He aided in development of the Surfagage, an industrial instrument for fine measurements of surface roughness of highly machined surfaces. Later he cooperated in combining the sensitive pickup device of the Surfagage with the diaphragm of a stethoscope to develop the Electro-Stethograph, an instrument that records the human heart's inaudible vibrations. He is currently specializing in studies to improve metal fatigue life and development of such automotive components as gears, brakes, and transmissions.

Mr. Bidwell is a member of Sigma Xi, honorary science fraternity, and the Society of Automotive Engineers.



LEWIS D. BURCH, contributor of this issue's "Notes About Inventions and Inventors," is a patent lawyer in the Patent Section of the Central Office Engineering Staff. He has held this position with the Patent Section since his employment in December 1949 and currently supervises patent applications, infringement, and other work relating primarily to automotive engines and chassis, and to factory machine tools and equipment. Mr. Burch received the B.S.M.E. degree from Purdue University in 1923 and studied law at George Washington University, Akron Law School, and Wayne University.

Previous to his initial General Motors employment Mr. Burch served as a

research engineer for the National Advisory Committee for Aeronautics; as a junior examiner for the United States Patent Office; as a patent lawyer for the Goodyear Tire and Rubber Company, Kelvinator Corporation, and the Borg-Warner Corporation. During and after the last war he also did labor relations and government war regulations work with Nash-Kelvinator Corporation.

During the period from June 1917 to April 1919 he served in the 28th and 1st Infantry Divisions of the United States Army as a private and corporal.

Mr. Burch's affiliations include membership in the Bar of the State of Michigan, the Supreme Court of the United States, and other federal courts. He is also a member of the Michigan Patent Law Association.

GODFREY BURROWS,

contributor of "The Development of New and Unique Manufacturing Techniques for the Production of Passenger-Car Frames," is master mechanic at Chevrolet Motor Division's Stamping and Frame Plant, Flint, Michigan.

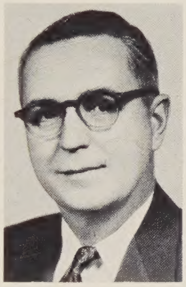
Mr. Burrows originally joined Chevrolet's Stamping and Frame Plant in 1923 after having previously been employed in the Engineering Laboratory and Testing Department of the Fore River Shipyard, Quincy, Massachusetts. He began his career with Chevrolet Motor as a die maker. He assumed his present position in 1953 after a series of promotions which included foreman of welding operations, supervisor of all welding processes, supervisor of plant layout, assistant master mechanic, and superintendent master mechanic.

Mr. Burrows' previous major projects include developmental work on the first resistance seam-welded gas tank made using Terne Plate, the development of the first tube-forming and welding mill put in operation at Chevrolet in 1928 for producing all sizes of tubing, development of suitable methods and welding equipment to meet the growing demand of production requirements, and recently the development of the first tube-forming and welding mill operations for the manufacture of automobile frames, of which he writes.

During World War II he was in charge of setting up the necessary procedures and processes for compliance with Army and Air Force specifications for the armored car and jet engines produced by Chevrolet and was also assigned to a special project between Chevrolet and Army Ordnance—the design of welding procedures for face-hardened armor.

Following World War II Mr. Burrows worked on the development of the first Chevrolet Power Glide Automatic Transmission. In his present capacity he is concerned with methods of process and manufacture for new developments.

Mr. Burrows is a 25-year member and past officer of the American Welding Society. He is active on several General Motors Committees, including the Master Mechanics Welding Equipment Committee, the Joining Processes Committee, and the Armor Welding Committee.



MILTON J. DIAMOND,

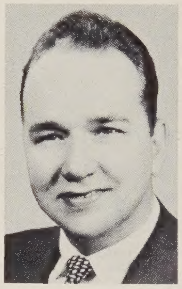
contributor of "The Utilization of Sonic Principles for Application to an Automatic Method for Casting Inspection," is a research engineer for Central Foundry Division, Saginaw, Michigan. In this capacity, he is currently engaged in development work for future processes relating to casting inspection and foundry technology.

Mr. Diamond was graduated from the University of Detroit in 1932 with the degree of Bachelor of Electrical Engineering. He was employed as a student engineer for the Consumer Power Company of Michigan and then joined General Motors in 1934 as a technician in the sand laboratory of the Saginaw Malleable Iron Division. This organization was re-named the Central Foundry Division in 1946.

Mr. Diamond assumed the title of research engineer in 1953 after a series of progressive promotions which included electrician, draftsman, and electrical engineer. In the latter capacity he was concerned with all electrical work connected with new plant construction for Central Foundry.

Mr. Diamond's previous projects have included developmental work on flame hardening machines for armored vehicle tank treads, automatic sprue-burning machines, and specialized flame hardening equipment. He recently has been concerned with developmental work pertaining to the inspection of castings for defects by electrical and magnetic methods. The result of one phase of his work is described in his paper.

Mr. Diamond is a member of the GM Committee on Non-Destructive Testing. He has had previous papers relating to magnetic and electronic methods of casting inspection published in *Electronics* and *American Machinist*. The Society of Automotive Engineers recently published his paper, "Magnetic and Resistance Methods Used in Non-Destructive Testing," which was presented at the S.A.E. Golden Anniversary Summer Meeting, June 1955.



MALCOLM R. McKELLAR,

contributor of "A Study in the Design of Sand Molded Engine Castings," is assistant motor engineer in the Product Engineering Department of Pontiac Motor Division.

Employed by Pontiac since September of 1937, Mr. McKellar began his work with General Motors as a General Motors Institute cooperative student. Graduating from General Motors Institute with a diploma in Automotive Engineering in 1941, he started full-time work at Pontiac Motor as a senior detailer in the Engineering Design Section. Since that time he has held various positions, including layout draftsman, senior designer, and design group leader. Early in 1955 he was promoted to his present position as assistant motor engineer. Although Mr. McKellar's experience has included varied automotive design projects, his work has been concentrated on engines. He is credited with having played an important role in the design of Pontiac's new V-8 engine, which was introduced with the 1955 model.

Mr. McKellar's continuous work at Pontiac Motor Division was interrupted in June of 1944, at which time he entered the United States Army. Having served as a combat infantryman with the Fourth Infantry Division in the European Theater, he was separated from the service in April 1946.

In recognition of his scholastic work at the General Motors Institute Mr. McKellar was elected to the Alpha Tau Iota honorary engineering fraternity. He is also a member of the Society of Automotive Engineers.

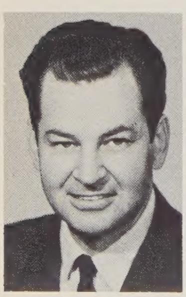
DAVID MILNE, contributor of "The Care and Handling of Liquids in Manufacturing Processes," is supervisor of Materials and Processes for the Production Engineering Section of the General Motors Manufacturing Staff.

Mr. Milne is a graduate of Wayne University, having earned the B.S. degree in chemical engineering in 1936. Five years later he was granted the M.S. degree from the same university.

In July of 1936 Mr. Milne joined General Motors as a chemical engineer in the Works Engineering Section of Fisher Body Division. The following year he was transferred to the Production Engineering Section of the Manufacturing Staff as a chemical engineer and was promoted to his present position in December 1952.

Mr. Milne entered the United States Army in December 1943, and his service assignments were primarily in the field of engineering. He was separated in March 1946 with the rank of Captain. His technical affiliations include membership in the National Society for Professional Engineers, and he is a registered professional chemical engineer in the State of Michigan.

Mr. Milne has had several papers published on various subjects concerning chemical engineering, principally in the field of industrial waste disposal.



LYMAN A. RICE, contributor of "The Development of a High-Output Carbon Pile-Type Generator-Regulator," is a staff engineer in the Engineering Department of Delco-Remy Division, Anderson, Indiana.

Mr. Rice was granted the B.S.E. degree in electrical engineering in 1935 from the University of Utah, and one year later he received the M.S.E. degree from the University of Michigan.

Upon graduation from the University of Michigan Mr. Rice began work with Delco-Remy as a student engineer in training in 1936. He served in various assignments until 1940, when he was transferred to the Engineering Laboratories for voltage regulator development training. In 1943 he was promoted to assistant section engineer. In 1950 Mr. Rice was promoted to his present position as staff engineer in charge of relay and regulator development. Prior to 1950 he was concerned primarily with the development of regulators for military aircraft and other heavy duty applications.

Mr. Rice's technical affiliations include membership in the Society of Automotive Engineers. His work in the field of automotive electrical systems has resulted in the granting of eight patents.

WILLIAM A. TURUNEN, co-contributor of "Firebird II: New Gas Turbine Powered 'Dream Car' Designed for Highway Use," has been head of the Gas Turbines Department of the General Motors Research Staff since November 1948.

Shortly after receiving the B.S.M.E. degree from Michigan School of Mines and Technology in 1939 Mr. Turunen became a member of the General Motors Research Staff. Subsequently he took post-graduate studies at General Motors Institute.

In 1942 he was called from the reserve into active service in the Army Engineer Corps. While in the Army he attended Columbia University and received his Master's degree in engineering administration in 1946. Mr. Turunen served in the Aleutians, and later, as a member of the Army Air Force, he was assigned to duty at Wright Field, Dayton, Ohio. He was discharged with the rank of Captain in December 1946 and returned to GM as a research engineer.

> **Contributors'** backgrounds vary greatly in detail but each has achieved a technical responsibility in the field in which he writes.

Mr. Turunen is author of two technical publications on gas turbine development, "Gas Turbines in Automobiles" (1949) and "Pinwheels or Pistons?" (1954), both of which were presented before the Society of Automotive Engineers. In 1953 he was co-author of another S.A.E. paper, "Measuring the Rate of Fuel Injection in an Operating Engine."

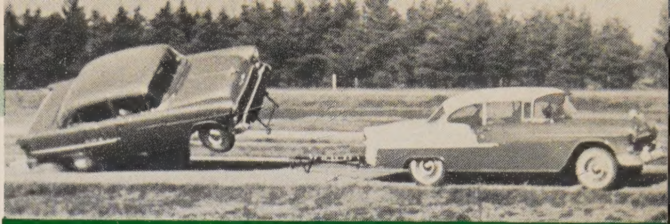
His technical affiliations include the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the Engineering Society of Detroit.

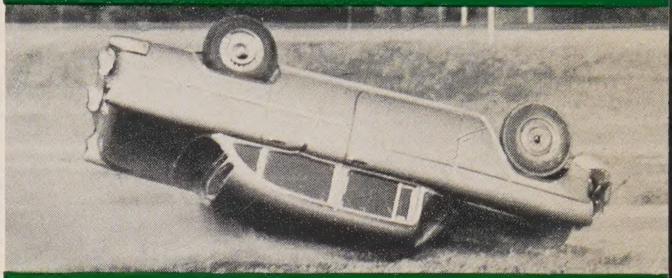
ROBERT F. ZALOKAR, who prepared the problem "Determine the Stiffness of a Fabricated Steel Supporting Structure for a Diesel Engine" and the solution appearing in this issue, is the supervisor of the Vibration Section of the Technical Department of the Cleveland Diesel Engine Division, Cleveland, Ohio.

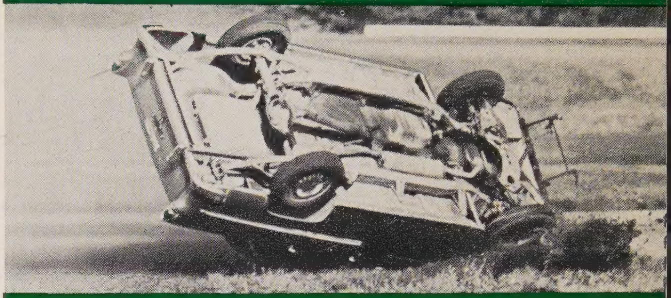
In September 1949 Mr. Zalokar enrolled at General Motors Institute in Flint, Michigan, as a student in the mechanical engineering program, starting with Cleveland Diesel Engine Division at the same time as a co-op student working in various assignments throughout the plant. During his last two co-op years he was assigned to the Technical Department. After his graduation in August 1954 Mr. Zalokar continued working in the Technical Department as a junior stress analyst. In November 1955 he was promoted to his present position of supervisor of the Vibration Section of the Technical Department. This section performs linear and torsional vibration studies of all the marine and generator Diesel engine installations, as well as investigating all new engine designs.

As a major portion of the requirements leading to his B.M.E. degree from General Motors Institute, which he received in 1954, Mr. Zalokar submitted a thesis "Investigation of Two-cycle Diesel Engine Foundation Design." Data for his report were completed while Mr. Zalokar was a co-op student in the Division's Technical Department. One section of his report on fabricated steel foundations was adapted by Mr. Zalokar and presented as a problem and solution in the GENERAL MOTORS ENGINEERING JOURNAL.

STUDIES FOR PASSENGER SAFETY



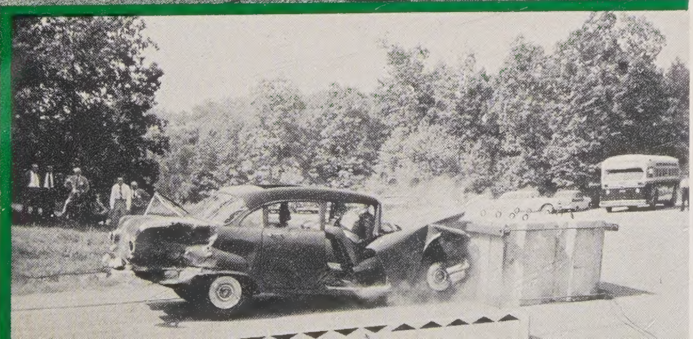




ROLL-OVER TEST

Structural strength is an important factor in the safety of an automobile body. This series of pictures shows how Fisher Body engineers conduct a roll-over test at the General Motors Proving Ground. A driverless car is towed toward a ramp at approximately 50 mph. At this point the towbar is released automatically, and the test car begins its first roll. The second picture shows the force of the initial impact being taken by the roof. In the third picture the car is starting its second roll. The fourth picture shows the car at the completion of the roll-over; at this point the engine was started, and the car was driven away under its own power. Damage to sheet metal, of course, is inevitable, but the primary purpose of the test is to study the strength of the basic body structure.

BARRIER IMPACT TEST



Barrier impact tests in which stock cars equipped with life-size manequins are crashed against a concrete wall were commonly used to evaluate such passenger safety devices as seat belts, seat belt attachments, and padded instrument panels. To avoid the complete destruction of a test car in such studies, GM's Proving Ground engineers devised a hydraulic snubbing device (left). One end of a steel cable is attached securely to the test vehicle at the height of the vehicle's center of gravity; the other end of the cable is attached to the snubbing device. A second vehicle (not shown) is used to tow the test car. When the drawbar pull reaches 1,000 lb, the coupling connecting the two cars is released automatically and the forward motion of the test car causes the cable to "bottom" in the snubber. The device employs a hydraulic cylinder with a variable relief valve which permits control of the impact deceleration up to 40 g's.

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